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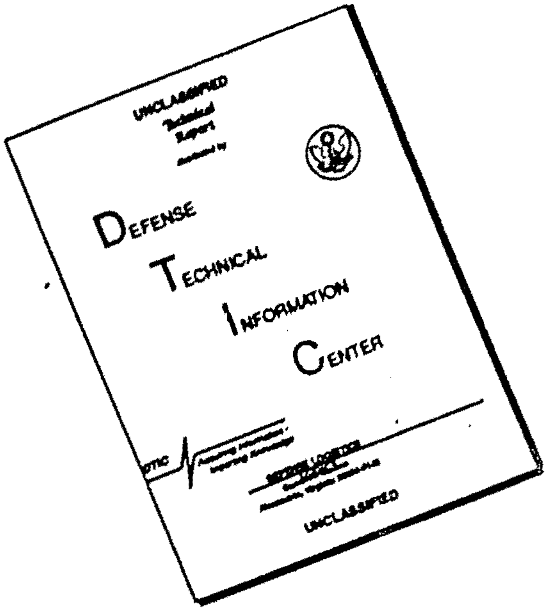

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DEPARTMENT OF THE NAVY
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WASHINGTON, D.C.

26 February 1954
Report No. 791
(Semiannual)
Copy No.

STEAM-JET CONDENSER FOR HYDRODUCTOR PROPULSION SYSTEM

Contract N6ori-10
Task Order I
Project NR 220 003

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26 February 1954

Report No. 791
(Semiannual)

RESEARCH, DEVELOPMENT, AND TESTING
OF UNDERWATER PROPULSION DEVICES

Contract N6ori-10
Task Order I
Project NR 097 003

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AEROJET-GENERAL CORPORATION

Azusa, California

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CONTRACT FULFILLMENT STATEMENT

This semiannual report is submitted in partial fulfillment of Contract N6ori-10, Task Order I, and covers the period 1 July through 31 December 1953.

INTRODUCTION

I. OBJECT AND DEFINITIONS

During this report period, research and development work has been conducted on the following underwater propulsion devices and fuels:

A. HYDRODUCT

1. The vapor-jet hydroduct is an underwater propulsive device in which "free" water, flowing through a submerged duct, either reacts with a hydrofuel to generate steam or is converted to steam by the heat of reaction of a solid propellant. Thrust is produced by the expansion of the steam to ambient pressure. The term "vapor-jet" is used to distinguish the device from hydroducts designed to operate on the expansion of a gas-and-water mixture.

2. The vapor-jet hydroduct is open at both ends, thus permitting a continuous flow of water through it. An initial forward velocity must be imparted to the hydroduct to build up ram pressure before self-operation can be obtained. Development work on the vapor-jet hydroduct has been carried out using Alclo propellant.

B. HYDRODUCTOR

An underwater missile may be propelled by a jet of high-velocity steam exhausting through a De Laval nozzle. However, as the missile goes down in depth and the back pressure increases, the steam velocity decreases until the thrust of the system deteriorates and the power plant ceases to operate. By condensing the exhaust with a steam-jet condenser, a low back pressure can be maintained and the performance of the missile can be increased and made relatively insensitive to depth of operation. Since the exhaust of the Alclo hydroduct consists of steam and solid reaction products, and is therefore completely condensable, a direct-contact condenser can be applied to the system. When the steam-jet condenser is applied to the hydroduct, the device is termed a hydroductor.

C. ALCLO-FUELED SUBMARINE POWER PLANT

1. The principles of the Alclo-fueled power plant are directly applicable to submarine propulsion. Alclo is a propellant containing both fuel and oxidizer. When burned within a recirculating gas cycle, it gives up its thermal energy to generate steam. The gas within the cycle does not take part in combustion but serves solely as a heat transfer medium. The products of combustion are all solid and are removed from the gas stream by means of a dust collector. A closed steam cycle, similar to a conventional steam-turbine power plant, is utilized to furnish the required shaft horsepower.

2. A submarine power plant burning this propellant would not require air for its operation, and thus can operate without surfacing for extended periods of time.

D. GASOLINE-AIR HYDROPULSE

The gasoline-air hydropulse is an underwater propulsion device in which the combustion products of gasoline and air are intermittently generated in a chamber adjacent to a duct and are admitted to the water in the submerged duct. Mechanical check valves are provided at the forward end of the duct. These open to permit the entrance of water during the low-pressure part of the cycle, and close during the high-pressure part of the cycle, causing the expulsion of water from the tailpipe.

E. SOLID-PROPELLANT GAS-TURBINE TORPEDO POWER PLANT

1. A small, high-speed impulse turbine powered by the gaseous discharge of a high-energy, slow-burning solid propellant is the heart of a deep-running torpedo power plant under development. The solid propellant is one of the AN-2000 series of Aeroplex formulations developed by this company, viz., AN-2091, which is characterized by its stable burning properties, a slow burning rate, and high energy content both on a volume and weight basis.

2. An operating power plant is being developed utilizing components available from previous development programs wherever possible.

II. SUMMARY

A. ALCLO HYDRODUCT

1. A series of runs made under almost identical circumstances have shown that, over most of the operating range of the hydroduct motor, chamber pressure, thrust, and specific impulse can be reproduced within $\pm$ 3%.

2. High-speed motion pictures were made of the ignition phase of special grains in an attempt to develop a better igniter which would assure a more uniformly burning face in a shorter period of time. Full-ignition time was reduced from 750 to 55 millisec.

3. Development work on the short chamber motor is complete and an optimum design fixed.

4. Pressure drop of the water entering the hydroduct motor has been calibrated.

5. The program of determining the storage properties of Alclo was continued.

B. HYDRODUCTOR

1. A series of runs have been made indicating the performance of the hydroductor with changing inlet conditions.

2. Some runs simulating starting for submerged firings have been attempted.

3. A new design employing condensation along a surface in the stream of the exhaust steam has been evolved and will be tested.

4. The high-pressure steam supply installed on the rotating-boom test facility has been adapted for study of the hydroductor and its power plant.

C. ALCLO-FUELED SUBMARINE POWER PLANT

A small steam generator has been constructed as a test unit for the proposed, closed-cycle, steam-operated submarine propulsion system. The development of firing methods for the propellant used has reached the stage where the steam generator has been successfully operated in a closed cycle for half an hour. The unit is ready for heat balance tests and additional work is still required to verify the calculated high efficiency of this steam generator. Work was terminated on this project at the direction of the Navy during this report period.

D. GASOLINE-AIR HYDROPULSE

This report includes a brief summary of all the development work done on the gasoline-air hydropulse from 1 April 1952 through 31 August 1953, and details of the work performed during the first two months of this period. Work on the free-floating Roots blower, acoustic mine sweeping, valve actuation, spark ignition, and fuel injection development is described. Work was terminated on this project at the direction of the Navy during this report period.

E. SOLID-PROPELLANT GAS-TURBINE TORPEDO POWER PLANT

1. A suitable gas generator was designed and fabricated for test-pit operation. The unit was designed for and has been operated numerous times at design conditions - 2300 psi pressure, 2300°F gas temperature.

2. A turbine and gearbox assembly developed for another program was modified for operation at the above-mentioned pressure and temperature conditions. A test pit previously used for turbine development work was modified as required to accommodate the solid-propellant power plant system.

3. Grains which burn for 2 minutes have been successfully tested. Utilizing experience gained from other high-pressure, high-temperature systems, no particular difficulty has been encountered in operating the solid-propellant system.

4. Turbine testing has been initiated.

5. Design of a mechanically operated turbine speed controller has been initiated.

III. CONCLUSIONS

A. ALCLO HYDRODUCT

1. Under normal circumstances, motor performance should be reproducible within $\pm$ 3%.

2. A new igniter has been developed that is considered satisfactory as far as igniting action is concerned. However, sufficient testing has not yet been conducted to evaluate its reliability.

3. The present, short combustion-chamber design gives results comparable to those obtained with the standard motor.

4. Pressure drop through the inlet of the hydroduct motor can be expressed as $\Delta P = 0.695 \, W_w^2$.

5. Test results indicate that storage of Alclo propellant for a period of 16 months at normal temperatures causes little or no deterioration. Results for a grain stored 15 months at 180°F show no change in specific impulse and a 12% decrease in burning rate. The equivalent storage time at ambient temperature for this grain is 57 years.

B. HYDRODUCTOR

1. The hydroductor performance has been measured in static tests for part of the range of expected free-running conditions.

2. Modifications to the rotating-boom steam supply system are 95% completed, after which a test program will be conducted.

C. ALCLO-FUELED SUBMARINE POWER PLANT

1. The main effort in the development of the closed-cycle steam generator was necessarily devoted to testing the various methods of burning the propellant used in this application. Basically, powdered and solid materials have been used. Both have their own advantages. The powdered materials appear

attractive from the standpoint of ease in handling and feeding by established pneumatic means. The results of burning, even though only partly successful so far, are inconclusive because of the small size of the test equipment, and tests on a somewhat larger scale should be made before final decisions are reached. By way of comparison, firing of pulverized coal is not satisfactory in small furnaces. The burning of the solid grain proved to be entirely satisfactory for small-scale testing. In larger, actual submarine installations, the high density of the propellant in this form would definitely be an advantage from the standpoint of storage, even though methods of conveying and feeding would require further study.

2. The successful operation of the test steam generator in a closed gas recirculating system has demonstrated that the system is thoroughly workable. There is every reason to believe that the development of the test unit is sufficiently advanced to enable continuous operation with little additional work. At this stage, a heat balance test run should prove the high performance possibilities of this steam generator.

3. The relatively small size of the existing unit has dictated its arrangement and, of course, it was intended as a convenient test installation. In scaling up the steam generator for submarine propulsion, modifications to the equipment would have to be made. The steam generator would consist of a radiant-type boiler and its furnace would be in form of a horizontal cylinder. The walls of the furnace would be completely water-cooled, forming the once-through, forced circulation boiler of the unit. Firing would be done at one end of the furnace, while superheater tubes would be located at the opposite end of the cylindrical furnace. The temperature of the recirculated gas leaving the superheater and entering the dust collector and recirculating fan can be quite high (perhaps on the order of 1000°F) as the overall efficiency is little affected, and considerable saving in size of equipment can be achieved by elimination of low temperature heads. The gas, still containing considerable heat, can be returned to the furnace around the burning equipment and through wall blowers that clean the furnace of any ash accumulations. Ash from the dust collector can either be stored or pumped overboard, as desired. Propellant storage requirements would depend upon the type of firing finally selected and methods of handling. The steam generator itself can be made quite compact and is consequently well suited for submarine installation.

D. GASOLINE-AIR HYDROPULSE

For satisfactory operation, the gasoline and compressed-air model of the hydropulse must have an extremely fast-acting air valve and a very rapid rate of flame propagation so as to cause a quick combustion pressure rise before the pressure of the precompressed charge diminishes. A satisfactory fast-acting valve has been built and tested. No satisfactory method of obtaining a quick pressure rise upon ignition has been developed.

E. SOLID-PROPELLANT GAS-TURBINE TORPEDO POWER PLANT

1. The practicability of a turbine-driven power plant utilizing energy from one of the AN-2000 series of Aeroplex propellants has been clearly demonstrated.

2. The extreme simplicity of a solid-propellant engine makes it a most desirable system for torpedo propulsion.

3. Simplicity of the system is accompanied by excellent reliability, ruggedness of components, and relative insensitivity to a wide range of operating conditions.

4. The propellant has an indefinite shelf life and is instantly available for use. Its specific impulse is one of the highest of those propellants suitable for turbine operation.

IV. RECOMMENDATIONS

A. ALCLO HYDRODUCT

1. More data should be gathered in the range of flows now indicated as not being readily reproducible. Tests should be made to indicate at what flow rates the missile runs.

2. The igniter now in use is in essence the first one used successfully. In the light of this, more work on igniter development would be helpful, especially reliability and reproducibility evaluation.

3. The program of determining the effect of storage under various conditions on the performance of Alclo propellant should be continued. This phase of the work is important from the standpoint of service evaluation.

4. Maintaining and improving the quality of Alclo propellant should continue. This includes quality control of the ingredients, rigid adherence to proper pressing techniques, and a systematic inspection of the final product. Uniformity of the propellant is considered essential if development of the combustion chamber is to progress properly and efficiently.

5. Classification of Alclo propellant should be done as soon as is practical. This would first involve a series of tests to be approved by the cognizant Government agency.

B. HYDRODUCTOR

1. The relation between performance and chamber pressure bears investigation since it may indicate certain optimum ranges of operation.

2. At present, the condensing water-to-steam weight ratio (β) for a static test can be varied by changing either flow independently. Since this is an artificial condition, its effect should be investigated.

3. The externally condensing hydroduct has distinct advantages and should be tested fully.

4. A comprehensive dynamic test program should be conducted to either verify the feasibility of the present hydroductor design under free-running conditions or to indicate the direction for future development work.

5. Thought should be given to a test-pit setup which would simulate depth for hydroductor operation. This would also facilitate investigation of starting and launching characteristics.

C. ALCLO-FUELED SUBMARINE POWER PLANT

1. Continuous operation and complete heat balance tests should be performed with the existing unit to definitely ascertain the attractive possibilities of this type of steam generator for the intended submarine propulsion system. Relatively little additional effort is required to accomplish this.

2. It is impossible to scale up the furnace capacity almost a hundredfold and be sure of its performance. In order to obtain data directly applicable to the design of an actual submarine installation, additional work is required. For this purpose, a conventional water-cooled furnace with physical dimensions comparable to those of the anticipated submarine installation should be fired with Alclo. Almost any of the widely available, package-type steam generators would do. This test unit need not be fired in a closed cycle at first, but should be studied mainly from the standpoint of furnace behavior during propellant firing and used in the final development of the propellant firing and handling equipment. Upon closing of the recirculating gas cycle, the unit can be used for the installation of automatic boiler controls and in training submarine personnel.

D. GASOLINE-AIR HYDROPULSE

1. Means of reducing the ignition delay should be devised so that the benefits of a precompressed charge can be fully utilized. Multiple ignition, a precombustion chamber, and other means of achieving this end should be considered and tested, and the best system developed for use in the test motor.

2. After the desired power is obtained from the existing motor, a multiple-ducted motor should be developed for ring-channel testing, and methods of utilizing it for the propulsion of surface craft should be considered.

E. SOLID-PROPELLANT GAS-TURBINE TORPEDO POWER PLANT

1. Gas generator testing should continue in order to evaluate more completely propellant performance at design operating conditions for this power plant.

2. Turbine testing should be expedited in order that efficiencies of this system may be determined.

3. An automatic turbine speed controller of the type which would be used in a torpedo should be fabricated and tested in conjunction with the turbine.

PART I

ALCLO HYDRODUCT

I. DESCRIPTION OF WORK

A. INTRODUCTION

1. For easy reference, the following figures are presented in the back of this report:

2. The static Alclo motors are operated as rocket motors, with simulated ram water injected into the combustion chamber from a pressurized water tank. Change in the water tank pressure results in various water flows, simulating different missile forward velocities. The motor is mounted on a thrust stand.

3. Water is flashed into steam in the combustion chamber by the heat released by the burning Alclo. The Alclo propellant, in the form of a solid cylindrical grain, burns like a cigarette. Turbulence devices are installed in the chamber to insure effective mixing of water, flame, and hot reaction products. The burning of Alclo produces essentially no gases.

4. Thrust is produced by expanding the steam through a nozzle. Thus, in effect, there is a continuous flow of free water through the duct.

B. STANDARD TEST MOTOR USING 3.75-IN.-DIA GRAIN

1. Because of a change of emphasis to the hydroductor motor during this report period, comparatively little work was done on the standard motor. No work at all was done on either the single-wall or the double-wall motor using 4.75-in.-dia grains.

2. Work was started early in the report period to check the reproducibility of runs in the motor. It had been noticed that the motor did not necessarily produce the same amount of thrust, although all external conditions remained the same. Since the composition of the grain is uniform and the same ingredients are used for many grains, it was not considered likely that the grain was the cause of this thrust variance. A more likely cause was the water sprayed into the motor. Since the amount of water is controlled by

a constant-flow venturi, the spray pattern assumed by the incoming jet was suspect. A special motor was therefore assembled where the water enters through four spray nozzles, a configuration that should insure a consistent flow pattern. Approximately 15 tests were run with this motor.

3. Another possible point where reproducibility might be affected is the igniter. Should the grain ignite unevenly or inconsistently, the run would be influenced. By study of the oscillograph records of pressure vs time for static test runs, it was observed that although the peak ignition pressure occurred at about 20 millisec, the chamber pressure did not reach full operating value until about 700 millisec later. High-speed motion pictures were made of the ignition phase of 16 special grains at atmospheric pressure equipped with standard and also special igniters. At least two tests were made on each of seven different igniters which were different in either the weight of igniter material or in detail design, or both. For the five most significant runs, still pictures were made from the motion-picture film for inclusion in this report. In order to facilitate the comparison of igniters, the pictures were made at identical time intervals; that is, at 10, 20, 30, 40, 60, 100, and 500 millisec. A composite of these photographs is shown as Figure 6. The first and second igniters shown are the standard missile igniter and the standard test-pit igniter, respectively. They are composed of an S-67 electric match, 0.2 gm of Alclo powder, and 6 Alclo pellets. In the first, these materials are held in the apex of a plastic cone by means of a paper diaphragm, and in the second, they are enclosed in a plastic envelope and fixed to the dome of a plastic enclosure. The motion pictures showed that for both these igniters, the Alclo pellets were all thrown out and away from the grain, some burning and others not. Therefore they did not contribute to the ignition of the grain to any appreciable extent. Ignition of the face of the grain was spotty; it required approximately 750 millisec for the flame to spread over the entire face. It was reasoned that improvement could be made either by holding the pellets in place near the face of the grain while they burned or by replacing the pellets with Alclo powder, which would ignite more easily and burn up completely while it was still near the grain. Both these changes were tried. Igniter No. 3, as sketched in Figure 6, has a metal cup which is held a fixed distance away from the face of the grain by means of four steel wires. A screen across the opening of the cup was provided to retain the six burning pellets until they accomplish their purpose. With 0.5 gm of Alclo powder to initiate the pellets, the ignition was smooth, quick, and apparently complete within 50 or 75 millisec. (The burning time of the pellets is about 130 millisec.) With only 0.2 gm of Alclo powder as the initiating charge, the ignition of the pellets was slow but still a considerable improvement over the standard igniters in that the entire face of the grain was ignited in less than 300 millisec. The fourth igniter had the same general configuration as No. 2 but, instead of having the Alclo pellets, it had one gram of Alclo powder. This igniter produced good ignition; the entire face was ignited in 55 millisec. The use of 2 gm of Alclo powder instead of one in this igniter resulted in detonation of the powder and consequently poor ignition. A fifth type of igniter was investigated in an effort to reduce the delay caused by the initiating match. In this igniter, which was otherwise identical to No. 4,

an S-75 squib was used instead of the usual S-67 match. The ignition delay of the S-75 is 1.7 millisec as opposed to up to 20 millisec for the S-67 matches. The S-75s are metal-jacketed and quite severe in their action. In one test the ignition was sparse and in the other test the Alclo grain was blown out of its holder due to the action of the squib. Probably with further development, this squib could be used to advantage because of its extremely short and consistent delay.

C. DEVELOPMENT OF SHORT CHAMBER

The development of the low L^* combustion chamber was completed. The design was satisfactory with regard to durability and protection of vital parts.

D. PRESSURE DROP CALIBRATION

In order that results of tests † on the free-running hydroduct can more readily be interpreted, a calibration of the pressure drop through the motor as a function of water flow was made using the static test facility.

E. BASIC STUDIES OF BALLISTIC PERFORMANCE

The program of determining the storage properties of Alclo was continued. Stored grains were tested using a standard test motor and standard running conditions. Their performance was compared to data obtained in the original control tests for those batches. Two parameters which together describe completely the performance of the propellant (all other things being unchanged) are the specific impulse and the burning rate. The specific impulse (lb thrust per lb fuel per sec) is a measure of the heat of combustion of the propellant and the burning rate is the rate of propellant consumption. Therefore these two parameters together pinpoint the rate of energy release, and hence the power output of the propellant. In the hydroduct, the specific impulse is influenced by many factors, such as water-to-propellant ratio, mixing efficiency, etc., and the spread of values of specific impulse is sufficient to obscure any decrease which may have been caused by deterioration of the propellant. The burning rate, however, is a much more sensitive parameter and it is not influenced appreciably by slight changes which may occur from run to run in the standard motor. Therefore the burning rate vs pressure characteristic of the propellant is used as the primary indicator of performance.

II. METHOD OF TESTING

A. STATIC TESTING OF ALCLO MOTORS

1. The Alclo motor is mounted on a parallelogram type of thrust stand and operated as a rocket motor. Water at pressures up to 1000 psi is supplied to the injector through a flow-limiting venturi from a pressurized water tank. This change in tank pressure, coupled with a variable line drop in the form of a plug valve, allows the water flow to be varied from 0 to about 8 lb/sec.

† Conducted under Contract Nonr-1002(00)

2. Thrust, chamber pressure, and water flow rate are recorded on a multichannel oscillograph using reluctance-type pressure pickups.

3. Water is sprayed over the outside of the motor to simulate the cooling of a free-running test.

B. PRESSURE DROP CALIBRATION

The nose and center sections of a spent, free-running round were attached to the water line from a pressurized tank. Static pressure at the inlet was measured, and since the injector was open to the atmosphere, the gage readings were taken as the pressure drop. Water flow was varied by means of a variable line drop in the form of a plug valve.

C. IGNITER IMPROVEMENT

Short increments of the standard Alclo formulation were used as the test grain. These had the standard 3.75-in. diameter and about 1.0-in. length. These special grains were restricted with cloth tape and Selectron resin on the sides and one end in order to allow burning only on the open end. The various igniters were fabricated and attached to the edge of the restriction of the respective grains by means of Selectron resin. The grain assembly was mounted horizontally in a fixture. A photoflash bulb (type SM) was connected in parallel with the electric match in the ignition circuit, and was included in the picture field. The ignition delay of these bulbs is less than 3 millisec and the first sign of illumination of the flash bulb was taken as being time zero. An Eastman high-speed camera was used, set to its maximum speed of 3000 frames/sec at F/6.3 with black and white film. A high-capacity ventilating fan was provided to blow the smoke away from the camera's line of sight. The camera was located at a distance of about 12 ft from the igniter-grain assembly and off to one side of the flaming axis. The camera motor was started 2.5 sec before the firing switch was thrown to allow the camera film to reach full speed. According to timing lines on the film, the frame speed at ignition varied from 2220 to 2640 frames/sec. Data reduction was aided by the use of an editing viewer which has a frame counter attachment.

III. RESULTS

A. STANDARD MOTOR USING 3.75-IN.-DIA GRAIN

The results of the tests for reproducibility are presented graphically in Figure 7, with pressure, specific impulse, and thrust shown as functions of the water-to-propellant weight ratio. As can be seen from this graph, the results are consistent to ± 3% above a weight ratio of 4.0. This is well within the experimental accuracy. At a weight ratio of about 3.5, there is a scattering of points. It can be shown theoretically that the curves become steep at this point where the chamber conditions correspond to saturated steam. Lowering the weight ratio again increases the performance so that, in effect, the curves can be considered to be smooth, with a region of poor consistency at 3.0 to 3.5 weight ratio.

B. IGNITER IMPROVEMENT

Two of the igniter types tried (Nos. 3 and 4) were shown to be a great improvement over the two "standard" igniters. Instead of producing sparse, spotty ignition of the face of the grain, which then takes approximately 750 millisec to spread over the entire face, these improved igniters produce full ignition in 55 millisec or less. Igniter No. 3 is probably the more positive and consistent igniter of the two; that is, it has a greater factor of safety because all its flame is directed against the face of the grain. There is probably not much difference as far as ignition delay is concerned under normal circumstances. Because of the advantage of simplicity of the Type 4 igniter, it was used in additional testing and the Type 3 igniter was set aside. The Type 4 igniter has been used in approximately 35 static hydroductor runs to date and the performance predicted by the motion picture films was substantiated.

C. DEVELOPMENT WORK ON SHORT CHAMBER

The design shown in Figure 5 has undergone repeated tests with excellent results. The performance is equal to that of the standard motor, and the carbon parts have been tested for four or five successive runs without failure.

D. PRESSURE DROP CALIBRATION

The results of the pressure drop calibration can be expressed as

$$\text{pressure drop (psi)} = 0.695\, W_w^{\,2} \qquad W_w = \text{flow (lb/sec)}$$

This is shown graphically in Figure 8.

E. BALLISTIC PERFORMANCE

1. An Alclo propellant grain which had been stored at ambient temperature (40 to 90°F) for a period of 16 months was tested. The specific impulse obtained was 329 lb-sec/lb, which may be compared to control values of 319 and 349. The burning rate obtained for the stored grain was 3% higher than the average for the control runs. This is considered to be within the experimental error of the control tests. It was concluded that storage for a period of 16 months at normal temperatures causes little or no deterioration of Alclo propellant.

2. An Alclo propellant grain which had been stored at 180°F for a period of 15 months was tested as above. The specific impulse was 335, which is considered normal. The burning rate with this grain was 12% less than that obtained in the control tests. This is the same reduction that was experienced after only 9 months of storage. It is not known whether further deterioration would occur in prolonged storage. Using the methods reported in Reference 1, the equivalent ambient (80°F av) storage time for this grain was calculated to be 57 years.

Report No. 791

PART II

ALCLO HYDRODUCTOR

I. DESCRIPTION OF WORK

A. INTRODUCTION

For easy reference, the following figures are presented in the back of this report:

B. SMALL-SCALE STEAM-JET CONDENSER

The entire test program on the small-scale steam-jet condenser is completely described in References 1 and 2. The experimental results and design data of this basic development program have been presented in a special report, Reference 3, which correlates all the information compiled throughout this phase of the work.

C. FULL-SCALE STEAM-JET CONDENSER

1. The full-scale steam-jet condenser is intended to fully simulate a free-running hydroductor motor in a static test installation. The unit has been designed flexibly enough to allow the interchange of components in order to arrive at an optimum configuration.

2. During this test period, runs have been made varying the water-inlet to condenser-throat area ratio (R) by changing the condenser-throat diameter. All these runs were made with virtually identical grains to eliminate any variation from that source. Performance of the unit was compared to parameters obtained in the small-scale steam-jet condenser.

3. Since limitations on test equipment do not allow testing with positive back pressure on the system (a condition that would simulate depth) all runs were made exhausting to the atmosphere. However, since it had been planned to start the free-running missile with the condensing section freely flooded, a series of tests were made in which the condensing section was filled with water and sealed by a rubber diaphragm.

D. EXTERNALLY CONDENSING HYDRODUCT

1. It may be possible to employ the hydroductor principle of depth insensitivity by taking advantage of the pressure distribution along a surface placed in the nozzle exhaust. Should this prove practical, a simple, depth-insensitive device would result.

2. A design for a test vehicle of this type has been evolved and static tests conducted to proof the configuration as a simple hydroduct. No facilities are available to determine the depth characteristics on the static setup since back pressure cannot be applied to the motor. It is planned to fire a free-running missile under Contract Nonr-1002(00) for this phase of the work.

E. FREE-RUNNING HYDRODUCTOR

The Hydroductor Mark I free-running missile has been completely fabricated and Morris Dam range firings have commenced. Range testing is being performed under Contract Nonr-1002(00). Results of the first firing are reported in Reference 4.

F. HYDRODUCTOR INVESTIGATIONS ON THE ROTATING BOOM

1. A high-pressure steam supply system (Figure 12) installed on the rotating-boom test facility for the study of condensable-exhaust rocket motor systems has been adapted for study of the hydroductor and its power plant. A simulated hydroductor model (Figures 13 and 14) has been fabricated, run through preliminary tests, and is in process of being instrumented so that combustion chamber pressure, condensing chamber pressure, and ram pressure of the water scoop discharge may be measured. Drag and thrust will be obtained from a 3-component balance on which the model is mounted.

2. To compare the performance of the hydroductor with that of the standard hydroduct, a simulated hydroduct model has also been fabricated (Figure 15). Both models utilize the nose and center section of a model tested in a previous program, and the present configurations are obtained by interchanging afterbodies. Drag and power plant performance of the two models will be investigated.

3. Although several dynamic tests of the hydroductor have been conducted, work thus far has been directed primarily toward obtaining steam-powered runs of sufficient duration. This has necessitated thorough insulation of the steam system with particular attention to the steam passages drilled through the model supporting strut. It is believed that this work has been satisfactorily concluded and, upon completion of the installation of pressure probes in the model, a comprehensive dynamic test program will be begun.

4. In addition to the measured quantities of thrust, drag, and the various pressures, the proposed program will utilize photographic studies of the model and power plant in operation. It is hoped that these data will be sufficient either to verify the feasibility of the present hydroductor design or to indicate the direction for future development work.

II. METHOD OF TESTING

A. FULL-SCALE STEAM-JET CONDENSER

1. The hydroductor condensing section is substituted for the regular tail section on a standard Alclo motor, which is run just as the motor for a hydroduct. Condensing water from a pressurized water tank is brought in just aft of the steam nozzle exit area. The flow can be regulated by adjusting the tank pressure in a range of approximately 150 to 185 lb/sec.

2. It must be noted that the condensing water-to-steam weight ratio β can be varied by changing either one of the two flows independently.

3. Thrust, chamber pressures, condensing pressure, and water flows are recorded on a multichannel oscillograph using reluctance-type pressure pickups.

B. EXTERNALLY CONDENSING HYDRODUCT

A standard hydroduct test motor has been adapted to conform with the internal configuration of the free-running missile design. It is tested just like a standard hydroduct.

C. HYDRODUCTOR INVESTIGATIONS ON THE ROTATING BOOM

1. When the steam accumulator tank has been heated electrically to the required pressure and temperature, the model is brought to the desired test velocity by the rotating boom. An oscillograph record of performance is started prior to the application of steam to the rocket motor and is continued throughout the powered run. This gives a continuous picture of the starting characteristics and of the steady-state running condition.

2. The operation of the steam system is as follows:

a. The tank, when fully heated, is initially filled to 90% of its total volume by saturated water at 1000 psia and 545°F. Part of this water can be flashed into low-pressure steam through the pressure regulating valve in the steam line (Figure 12). The heat of vaporization is obtained from the water remaining in the tank, which gives up its excess heat as the tank pressure drops. The present accumulator tank, using a top pressure of 1000 psia, is capable of supplying steam for approximately 15 sec at 300 psia at a flow rate of 2.0 lb/sec.

b. The steam supply is started to the model, and the simulated combustion chamber pressure is regulated by applying a control pressure to the dome of the steam regulating valve. To minimize the time required for this operation, an air storage tank was incorporated into the system. This tank is charged to the desired pressure through the small pressure regulating valve in the air line and through solenoid valve No. I. During this charging process the air tank is sealed above and the steam regulating valve is vented through solenoid valve No. II. With the air tank fully charged, a run is started by closing valve No. I and opening valve No. II to pressurize the steam valve dome. Shutdown is accomplished by venting valve No. II. Once the desired air tank pressure is set on the air regulating valve, operation can be controlled remotely by the rotating-boom operator.

3. The initial dynamic testing will consist largely of investigations of power plant performance at various forward velocities. Additional work and improved testing techniques will be based on the results of the first phase of the program.

III. RESULTS

A. FULL-SCALE STEAM-JET CONDENSER

1. In order to compare results obtained on the full-scale steam-jet condenser with those of the small-scale unit, it was found expedient to calculate a new parameter, η_F, which is the ratio of the actual measured thrust and the theoretical thrust calculated for similar conditions. This quality is closely related to the η_T reported in Reference 3.

2. With the condensing water-to-steam weight ratio (β) held constant at about 27.5, R was varied from 0.90 to 0.70 in 0.05 increments. It was found that the motor started well at R = 0.70. This ratio was then used for a series of runs. The results of these tests are shown in Figure 16, together with the data from the small-scale unit, where it can be seen that the trend exhibited is similar. It would not appear beyond reason to suspect that chamber pressure would affect the value of η_F at a particular β. The tests on the small-scale unit were all made at a chamber pressure of 165 psia, whereas the full-scale runs are in the neighborhood of 250 psia. As yet, no work has been done to establish this pressure dependency.

3. Those tests started with the condensing section flooded showed that the motor would start against atmospheric back pressure. There is, of course, no proof that it will start against more head and when emptying into an "infinite" reservoir.

B. EXTERNALLY CONDENSING HYDRODUCT

Only a few tests have been conducted, but a preliminary design has been made that permits all-aluminum construction without damage during a full-duration run.

PART III

ALCLO-FUELED SUBMARINE POWER PLANT

I. INTRODUCTION

A. "Proposal for the Development of Alclo Submarine Propulsion Unit," submitted on 21 July 1950, offers a program to develop a steam power plant that will permit a submarine to operate submerged for extended periods of time. The novel feature of this propulsion system is the steam generator. It is designed to burn an Aerojet-developed propellant called Alclo, which upon combustion leaves substantially no gaseous products. The released heat is used to generate steam which, through suitable propulsion equipment, provides the motive power for the submarine.

B. A full description of the principal features of the proposed installation is given in the above proposal.

C. In order to carry out the development of this power plant, a small test steam generator having a capacity of approximately 500 lb of steam an hour has been constructed. The test generator is shown in Figures 17 and 18, and in most respects it duplicates the schematic arrangement of the original proposal as shown in Figure 19. A brief description of the unit and its expected operation will make these figures clear.

D. Aluminum as fuel and potassium perchlorate ($KClO_4$) as oxidizer, both in powdered form, are stored in separate containers. The bottom of each container has an electrically driven feeder which drops each constituent into a gas stream that carries it to the burner. The burner delivers the two streams into the furnace where mixing and burning occurs. The boiler located above the furnace absorbs the heat of the flame by direct radiation. Gas that is recirculated throughout the system enters the furnace through openings in the refractory walls. It cools the refractory and carries the absorbed heat to heat-recovery surfaces not directly exposed to the flame. Ash formed from the combustion of propellant has two constituents: potassium chloride (KCl) and aluminum oxide (Al_2O_3). The chloride has a low melting temperature (1432°F). It slags in the furnace, eventually dropping into the slag tank, while the oxide in the form of fine powder is carried by the recirculating gas and is removed from the system by the dust collector. The economizer (or second boiler) is installed to lower the temperature of gas entering the recirculating fan. The fan returns the gas to the furnace and the cycle is repeated. A portion of the same gas is used to blow the fuel and oxidizer through the burner.

II. METHOD OF TESTING

A. BOILER PRESSURE PARTS

1. The early, preliminary tests were conducted with the aid of a small generator made of coiled tubing forming a simple, water-cooled furnace and boiler. Inside this furnace Alclo grains were burned. Information and data obtained indicate a high heat absorption rate, but were otherwise mainly in the form of qualitative visual observations. These aided the selection and arrangement of the equipment as finally installed.

2. For steam generating in a closed-cycle system, two locally manufactured Bessler Corporation boilers were incorporated into the test setup. Each of these units forms a separate, once-through, forced circulation boiler. The boiler consists of continuous 0.840-in.-OD 16-gage stainless steel tubing wound in six flat coils forming the boiler, and ten coils forming part of the walls of the combustion chamber. Each unit is capable of generating steam at a rate of 500 lb per hour at 150 psig and 700°F. The second of the units was added to protect the recirculating fan from high gas temperatures at higher firing rates.

3. The boiler water feed pump was acquired from the same boiler manufacturer. It is a two-piston reciprocating pump. A motor drive with the installed V-belt ratio fixes its capacity at 485 lb per hour, but by suitable water recirculating connections the capacity may be varied to any desired figure.

B. FURNACE

1. Refractory furnace walls were selected mainly because of their simplicity in construction and ease of maintenance. However, many factors were considered before the final arrangement of the furnace was decided upon.

2. The furnace was built with the intention of burning the propellant in suspension. This kept the high-temperature Alclo flame, with its high local heat-release rates, away from walls and burning equipment in the form of grates and retorts. The relatively small size of the unit permitted high furnace heat-release rates and the figure of 268,000 Btu/hr/EPRS (Effective Projected Radiant Surface) at the full rating of 485 lb of steam per hour does not appear excessive.

3. The refractory furnace allowed a simple means of admitting the recirculated gas into the furnace. The gas enters the furnace in such a way as to protect the firebrick by a continuous scrubbing action and, by a rotating motion at the walls, it adds turbulence and effective length to the Alclo flame. Intermittent firings totaling well over 6 hr showed no ill effects to the refractory due to the high heat concentrations.

4. The bottom of the furnace is provided with an opening to permit slag runoff during furnace operation. In the first arrangement, as shown in Figure 17, this opening appears to be in a somewhat cool portion of the furnace; but in view of the low melting temperature of the slag, some alterations to the furnace were anticipated as the tests progressed. The furnace as subsequently modified is shown in Figure 20, and the slag tap appears in a more desirable location.

C. DUST COLLECTOR

To remove the products of combustion, a cyclonic dust collector with multiple small tubes was built. Like other conventional units of this type, the collector makes use of centrifugal force to separate the fly-ash from the recirculating air stream. The ash-laden air enters the space between two concentric tubes (2-1/4-in. OD and 1-1/2-in. OD, both thin-wall) where suitable vanes give it a spinning motion. The heavier ash then hugs the outer wall and continues downward while the air turns into the inner tube to leave the dust collector. Twelve collecting tubes have been installed but, by suitable blocking, the number in use can be varied to improve collecting efficiency. All tubes discharge into a large hopper that will permit operation for half an hour. Continuous operation can be had by washing down the hopper with water.

D. RECIRCULATING FAN

Preliminary performance calculations show that, at an evaporation of 485 lb of steam per hour and an assumed recirculation ratio of gas to propellant of 7 to 1 by weight, the required fan capacity is 875 cfm. The immediate availability of a 1000-cfm and 16-in. w.g. fan prompted its installation. The high static pressure available eliminated the need for a booster fan to feed the powdered propellant into the furnace.

III. CALCULATED PRELIMINARY PERFORMANCE DATA

A. Preliminary heat balance of the complete unit was calculated to serve as a guide in the selection of test equipment and future operation. In the absence of direct information, a number of assumptions had to be made in order to simplify the calculations. The most important of these was the furnace heat absorption rate. At 485 lb of evaporation, the heat released in the furnace is 268,000 Btu/hr/EPRS, which includes heat fired and heat returned by the recirculating gas. This would be considered conservative in a unit of this size. Calculations indicate that an absorption rate of 75,000 Btu/hr/EPRS can be expected, and this figure seems reasonable. The heat release per cubic foot of furnace volume has little meaning in a unit of this size, and the necessary requirement is to provide sufficient volume to physically accommodate the flame in such a manner as to avoid flame impingement on walls and boiler. The ratio of recirculated gas to propellant of 7 to 1 by weight has been arbitrarily fixed for the purposes of design and calculations, but it can be varied as desired during operation by adjusting the recirculating fan inlet and outlet dampers. Steam temperature leaving the boiler is directly dependent upon the firing rate.

B. The results of these calculations and assumptions are given in Table I at the end of this report. The tabulation gives values for two conditions: with and without duct work and surface insulation. Because of the low-temperature fan installed for the early tests, the unit will remain uninsulated. At a later date, when it becomes necessary to verify the high efficiency of the steam generator, a high-temperature fan impeller will be installed and the unit will be completely insulated for heat balance runs.

IV. RESULTS

A. METHODS OF BURNING ALCLO IN TEST STEAM GENERATOR

1. Burning of a fuel directly combined with an oxidizer is new to the steam generating field; consequently the utilization of a propellant within a furnace may call for methods of handling and combustion unlike those of conventional fuels. It is with this in mind that the various methods of burning Alclo had to be tried. One of the primary factors to appreciate is the extremely high, local heat concentrations possible with a theoretical Alclo flame temperature of 7100°F. Direct impingement of the flame on a high-quality refractory brick starts melting it almost instantly. Of course, the recirculated gas could temper the gas leaving the furnace to any desired figure, but direct contact of any equipment with the flame must be avoided.

2. It appeared, that the best way to avoid the deleterious effects of the high flame temperature would be suspension firing of Alclo in the furnace. By means of a suitable burner, the propellant can be suspended and burned in the atmosphere of the furnace similarly to powdered coal. In a preliminary setup, Alclo grains were crushed to a size to pass through a 20-mesh screen and then blown through a tube by means of controlled compressed air. Ignition of the suspended Alclo at the end of the tube was obtained by means of a butane gas burner. The granulated Alclo burned easily in this manner with flame lengths varying from a few inches to several feet depending upon the combined effects of rate of feeding and tube efflux velocities. This method of firing Alclo, though thoroughly workable, was used only for a short time because of the inherent danger of backfiring into the feeding hopper.

3. The use of separate, powdered Alclo constituents eliminated the need of handling material combined with an oxidizer and reduced the danger of a backfire. In this arrangement, powdered aluminum and potassium perchlorate ($KClO_4$) were fed mechanically from separate containers into separate air streams from the recirculating fan. Two alternatives appeared to be practical. In one, the mixing of the two streams is done at an outlet of a suitable burner in the relatively unconfined volume of the furnace (Figure 21). In the other, the two streams are led to one end of a burner barrel and travel through the burner with a rotating or swirling action to promote intimate mixing (Figure 22). The burning in both cases occurs in the furnace and ignition is started, as above, with a butane torch. Both methods were extensively tested. The mixing outside

the burner was favored, as it was completely free from burner flashback. In the case of burner barrel mixing, deliberately induced flashbacks have on several occasions damaged the burner, even though the material in the feeding hoppers remained unaffected. Both types of burners easily maintained their own ignition, and firing periods up to half hour in duration were maintained without ignition torch support. The externally mixing burners were used with a combination of various outlet tube sizes (3/8-5/8, 1/2-3/4, 5/8-1, 3/4-1-1/4, 1-1/4-2 in.). The increased mixing zone of the larger burners gave a better controlled flame and, to all appearances, more complete combustion. The internally mixing burners were built in two sizes of tubing, 1-in. OD and 1-3/8-in. OD. The outlet nozzle sizes varied from 1/4 to 1 in., the optimum for a firing rate of 1-1/2 lb of mixture per minute occurring at an outlet nozzle diameter of 1/2 in. All burners were made to work well within their own range, but burning of the powdered materials, though basically successful, proved to be difficult in another way. Fluctuations in the feeding of these materials resulted in some of them passing through the flame unused and collecting in various areas of the furnace. This collected material would ignite at times, and the resulting unpredictable puffs made the closing of the gas cycle inadvisable. After spending considerable time in an attempt to eliminate this incomplete combustion, the conclusion was reached that at the relatively low feeding rates used (1 to 2 per minute) a certain amount of fluctuation or "slugging" is unavoidable and in order not to delay the development of the test unit other methods of firing should be used. Figure 23 shows the feeder and burner assembly.

4. Burning a solid grain definitely eliminated the difficulty of continuously proportioning and mixing the Alclo ingredients. It resembles suspension firing somewhat, inasmuch as the Alclo flame does not impinge on, nor is it in contact with, any burning equipment. In the final arrangement the propellant is pressed into a 0.750-in.-OD copper tube, approximately 6 in. long, to form a solid stick or grain. The copper tube acts as a side restrictor for the burning surface of the grain. The grains are mechanically fed into the furnace through a closely fitting opening and form a train that burns continuously like a cigarette (Figure 24). Ignition is started by means of an electric match. After a few preliminary trials the burning appeared so successful that the recirculating air cycle of the unit was closed and subsequent testing was done in a closed unit. A few difficulties which were encountered in carrying the burning across the butted ends of the grains were finally traced to the contamination of the grain by the die lubricant during pressing operations. Time did not permit further development of this type of firing for the intended application, but satisfactory closed-cycle performance in short tests totaled well over half an hour. There is no doubt that continuous operation of the unit could be readily obtained with some additional work.

5. An entirely different approach to burning the constituents that go into making Alclo was tried in the following scheme. Approximately 2 lb of aluminum were melted and heated to a temperature of 1750°F in a retort made of a carbon tube with 4-1/2-in. OD, 1/2-in. wall, and 6-in. length. Grains of

potassium perchlorate were added to this molten puddle and, with grains sufficiently small, reaction with aluminum took place, the surface of the aluminum glowing with the brightness of an Alclo flame but without visible formation of smoke. Higher aluminum temperatures would have undoubtedly permitted using larger grains of $KClO_4$, which under the above conditions too quickly absorbed the heat of the aluminum in the endothermic reaction of breaking down the potassium perchlorate. The tests were simply made and can be credited with only partial success. Efforts at the time were turned to other methods directly applicable to the existing steam generator, and a few comments concerning them are in order here. The main advantage appears to be that the Alclo constituents are handled in solid, dense forms. The combustion reaction takes place in a suitable retort completely surrounded by steam-generating water walls, as no recirculated gas is used. Aluminum is replenished in the solid form, and the rate of reaction is controlled by the proper addition of solid potassium perchlorate in a way that will overcome the surface tension of the molten puddle. The mass of the aluminum is used to control the puddle temperature. All products of combustion can be melted and slagged. As mentioned above, this method was only briefly tried with some success, but additional work would be required to reach conclusions as to its ultimate value.

B. OPERATION OF THE STEAM GENERATOR

1. During the earlier stages of powdered Alclo burner development, the steam generator was tested on several occasions by firing the powdered Alclo mixture under the test boiler. With the boiler gas outlet connected to an outside stack, the unit was sufficiently preheated with a butane burner to heat the setting and start steaming. After this preliminary conditioning of the furnace, Alclo mixture at a rate of 1.5 lb/min (optimum burner performance at that time) was turned on and ignited. With the butane burner off, the generator performed satisfactorily, and at an estimated water flow of 200 lb/hr and 125 psig, the steam temperature leveled off at 460°F. At somewhat lower water rates the steam reached 550°F. Three runs of about 10 min each showed no ill effects to the unit due to the high Alclo flame temperature. The operation of the steam generator firing the Alclo mixture was considered a success, even though it was not possible at the time to close the gas recirculating cycle because of incomplete burning.

2. As the boiler testing progressed, it became apparent that in order to further the development of the closed cycle, more controlled means of burning Alclo would have to be used. Burning a side-restricted solid grain proved to be satisfactory in this respect. Preliminary firing showed the necessity of sealing all openings in the suction portion of the cycle because of excessive "smoke" leakage. After this was done, the unit was repeatedly fired with little or none of the smoke escaping to the atmosphere. The boiler water rate was varied between runs. The firing rate of about 1 lb/min of Alclo was fixed by the grain size and its burning rate. Because of some grain-to-grain ignition difficulties, runs of only 4 min duration were obtained. This was not

sufficient to permit steaming, although starting with the unit cold, the water leaving the boiler approached 200°F. During these firings the boiler tubes became coated with powdery Al_2O_3 ash which was allowed to accumulate in order to study its behavior and effects. Accumulations during half an hour of firing are shown in Figure 25, and are an average of 0.1 in. thick. This ash does not appear to be in any way tenacious and light blows with compressed air easily clean the surface. Almost any form of soot blowers could keep these surfaces clean. The dust collector collected a full hopper of this ash. Figure 26 is a view of the dust collector inlet after a half-hour of closed-cycle operation. Figure 27 is a view of the recirculating fan after a half-hour of closed-cycle operation. The furnace wall facing the burning Alclo shows a thin (approximately 1/4 to 1/2-in.-thick) layer of slag of approximately 10-in. diameter. Apparently because of continuous ash recirculation with the gas, the furnace atmosphere carried considerably more ash in suspension than in open firing, and this tends to absorb the KCl without any visible separation aside from the furnace surface mentioned above. Neither the ash nor the slag appears to present any removal problems.

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PART IV

GASOLINE-AIR HYDROPULSE

I. DESCRIPTION OF WORK

A. INTRODUCTION

Development work on the gasoline-air hydropulse was resumed 1 April 1951 and continued through 31 August 1953. The objective was to increase the chamber pressure, thrust, and power output of the motor by precompression of the charge and by increasing the cycling rate. This report comprises a summary of all the work performed and includes details of the work during this report period.

B. FREE-FLOATING ROOTS BLOWER

1. A free-floating Roots-type blower was mounted on top of the carburetor. This blower was to be driven as an air motor by the incoming air during the low-pressure part of the cycle, and then to act as a compressor to ram the charge to a pressure above ambient just before the spark ignited the charge.

2. In operation, the desired results were not achieved. The pressure-volume diagram showed that sufficient energy was available to the blower to compress the charge, but the inertia and friction of the blower prevented the rapid acceleration necessary to absorb the energy in the available time. The slow blower speed actually "starved" the motor for air.

3. The mass of the rotors could not be reduced without weakening them structurally, but the friction was reduced by lapping the teeth of the timing gears, and replacing the friction shaft seals with clearance labyrinth seals. The clearance leakage was reduced by tin-plating the rotors. These measures helped, but failed to produce the necessary rapid blower acceleration.

4. A final attempt to increase the rate of acceleration of the blower was made by tuning the system to the desired frequency. A spring acting as a coupling was used to fasten a ball-bearing-mounted flywheel to the blower. The polar moment of inertia of the flywheel and the constant of the spring were selected so that the system (consisting of blower, spring, and flywheel) was resonant at 7 cps, the operating frequency of the hydropulse. It was believed that by operating the system at resonance, the blower response could be improved. The improvement was very slight, so that the motor lacked sufficient air, even for normal running. The free-floating Roots blower method of obtaining precompression was abandoned.

C. ACOUSTIC MINE SWEEPING

The use of the gasoline-air hydropulse in acoustic mine sweeping was proposed, as the motor is a simple source of low-frequency underwater sound. The motor was taken to the Naval Ordnance Test Station at Morris Dam, California, and demonstrated for personnel of the Office of Naval Research and the Georgia Institute of Technology. The low-frequency component of the signal was found to be too low in amplitude to be useful for acoustic sweeping gear.

D. GASOLINE AND COMPRESSED AIR MOTOR

1. It was decided to develop a motor to operate on compressed air and gasoline. For testing, the motor was to be mounted at the 40-ft radius of the rotating boom in the ring channel. Since no air compressor is available on the boom, compressed air was stored at 2300 psi in 20 standard, steel oxygen bottles mounted on the boom. Wherever possible, existing facilities on the boom were used for actuation of the various valves and for instrumentation.

2. A new motor was designed, built, and designated as the Mark I gasoline and compressed air hydropulse. It followed the proven geometry of the latest model of gasoline-air hydropulse, except that it was made stronger to withstand the higher pressures to be developed. The combustion chamber was smaller because the charge was compressed. A sectional assembly drawing of the motor is shown in Figure 28 and the assembled motor complete with fairing is shown in Figure 29.

3. There was a possibility that the internal geometry of the motor could be simplified into a simple, round duct. It was also desirable to determine if the flap valve might be eliminated. This was most economically achieved by modifying an existing direct hydropulse (lithium-fueled) for operation with gasoline and air. A sectional drawing of this motor, which was designated the Mark II, is shown in Figure 30, and it is shown assembled with the strut fairing in place in Figures 31 and 32. The straight duct allowed room under the motor skin for the air valve and the chamber pressure pickup, so that the motor had a much thinner strut fairing than the Mark I.

4. The bulk of the development work was done on the Mark I motor, and the description of work done refers to this motor, unless specifically stated otherwise.

E. AIR VALVE DEVELOPMENT

1. The hydropulse cycle required that the air be valved into the combustion chamber very rapidly and with low pressure drop through the valve. This necessitates a large, but rapid-acting valve. The first valve was of the balanced, double-beat poppet type, sealing on one fixed and one resilient seat. To utilize existing boom facilities, a hydraulic system of

valve lifting, designed around the Bosch plunger-type oil pump, was used. The pressure from the Bosch pump was insufficient to overcome the valve spring pressure, so the Bosch pump oil was used to operate a pilot valve, which controlled oil flow from a pressurized tank to lift the main air valve. The system worked fairly well, and would give a 7/16-in. valve stroke at cyclic rates up to 12 per second. However, the system was very inconvenient to operate because of the number of auxiliary components. A schematic diagram of the boom hydraulic-pneumatic system using this method is shown in Figure 33.

2. The valve was well balanced, so it was possible to reduce the valve spring pressure and the hydraulic lifting area of the valve stem to permit direct actuation by the Bosch pump. Operation was better than before, with considerable simplification, as shown in the new schematic diagram, Figure 34. Part of this simplification was made possible by the adoption of continuous fuel injection as described in Section G of this part.

3. The Mark II motor was equipped with a conventional single-beat poppet valve, hydraulically lifted by 1100 psi oil from a Vickers plunger-type oil pump. Oil flow to the valve was controlled by a commercial three-way solenoid valve. An accumulator close to the solenoid valve maintained the oil pressure constant. This system worked quite satisfactorily and was used on this motor throughout the entire testing period. Figure 35 is a schematic diagram of this valve actuation system.

4. The double-beat valve on the Mark I leaked slightly from the start, and this leakage became progressively worse. Much time was spent lapping and fitting the valve so as to maintain even pressure on both seats. Since the conventional poppet valve on the Mark II motor was working well, and sealed with zero leakage, a similar valve was installed on the Mark I. The valve is shown in cross section in Figure 36. The actuation system was the one shown in Figure 35. This valve system remained in use until the valve was modified for direct cam actuation during the last two months of work.

F. SPARK IGNITION DEVELOPMENT

1. The new motor was first operated with the spark ignition equipment from the old gasoline-air hydropulse. The spark was supplied by a 12-volt automotive ignition coil and intensified somewhat by an aircraft ignition vibrator.

2. For ignition of gasoline vapor under water, a spark of unusually high energy is desirable. Therefore, a 110-volt primary, 10,000-volt secondary oil ignition transformer was substituted. The spark was intense and reliable, but was of such high voltage that the underwater ignition cable was subject to occasional insulation failure. Also, the spark fired on the first voltage peak of the secondary circuit and timing could vary as much as 0.008 sec. Closer spark timing was desirable.

3. A condenser discharge system with the condenser charged by a simple full-wave vacuum tube rectifier was built and proved entirely satisfactory. It furnished a high-energy spark of higher amperage but lower voltage and exact spark timing was possible. Figure 37 is a schematic diagram of this system.

G. FUEL SYSTEM DEVELOPMENT

1. Many types of fuel injector nozzles were considered and several types were tested in an endeavor to find one that would handle the large quantity of fuel required and still give a finely divided spray. One difficulty was encountered with all the injectors. The streamlined skin of the motor required that the combustion chamber be quite shallow, and no matter which way an injector was pointed, a considerable portion of the gasoline spray collected on the chamber walls, where it formed a liquid film and vaporized slowly. Fairly steady firing was finally obtained by using an air atomizing injector which gave a fine fog close to the nozzle tip, but considerable liquid runoff was still present with resultant excessive fuel consumption.

2. The point of fuel injection was moved upstream of the air valve into the air intake pipe. However, the fuel spray still collected on the walls of the pipe, giving slow vaporization and poor combustion.

3. A wick type of fuel vaporizing device was installed on the Mark II motor, consisting of three horizontal metal screens covered with loosely woven cloth onto which gasoline was sprayed continuously. A good supply of fuel vapor was formed and, for the first time, good steady firing resulted. The device was very simple and eliminated the need for timing the fuel injection since fuel flowed continuously, but the wicks were soon damaged mechanically by the high-velocity air in the intake pipe.

4. The principle of the wick vaporizer was utilized in more rugged form in a plenum chamber, or enlarged section of the intake pipe. A wick made of parallel screens of 40-mesh copper cloth, soldered to supporting rods, was installed. With fuel sprayed onto this wick continuously, vaporization was good and both the Mark I and II motors gave steady firing when equipped with this device. The Mark I produced a maximum chamber pressure of 140 psi and the thrust was measured at 70 lb when running at 4.5 cps. However, an occasional backfire would severely damage the screens. The principle appeared desirable, but something more rugged was necessary.

5. A cylindrical double-wall screen of heavy stainless steel wire mesh was installed just inside the wall of the plenum chamber, and the annular cavity of the screen was filled with porous ceramic pellets. Fuel was sprayed continuously into the chamber through an atomizing injector. An electric-motor-driven fan turbulator caused a continuous air flow outward onto the screen and pellets. Any liquid draining off the screens was caught in a

sump, delivered to the inlet of a miniature centrifugal pump on the lower end of the fan shaft, and pumped back up to the injector. All liquid fuel was thrown out against the screen by centrifugal action of the fan blades so that only fuel vapor passed through into the combustion chamber.

6. This system of fuel injection appeared quite satisfactory and was used for all subsequent testing. Measurements of the air temperature above and below the plenum chamber showed that the latent heat of vaporization of the gasoline was being supplied. Maximum chamber pressure was increased to 260 psi and thrust increased to 145 lb at 4.5 cps.

H. FLAP VALVE STUDY

1. Although the Mark II motor was the first to produce steady firing, the Mark I gave much better results when it too was equipped with a plenum chamber vaporizer. The Mark II would operate only at low cycling speed of 3 to 4 cps and at injection air pressures below 40 psi. In the Mark I motor, the gas bubble in the duct was protected from the rapidly moving water by the open flap valve. No such protection was available to the bubble in the flapless Mark II, and it was believed that at higher frequencies and pressures, the water was mixing with the bubble.

2. The last part of the testing was done only with the Mark I motor.

I. CAM-ACTUATED VALVE

1. The Mark I motor fired steadily with maximum chamber pressure of about 250 psi, whereas 500 to 600 psi is desired. The oscillograph records of chamber pressure showed that the pressure of the injected air bubble dropped to about half its initial value before explosive combustion occurred. Also, the air control valve opened rapidly enough, but closed too slowly. Analysis of the dynamics of the hydraulic valve actuation system showed that the response of the solenoid pilot valve was responsible for the slow closing of the main air valve. A late spark was a necessary result, because the ignition spark cannot be fired before the valve is closed without danger of backfires. If the air valve could be made to close very rapidly, it was believed that the explosive combustion could be initiated before the injected air pressure diminished appreciably.

2. Various methods of obtaining the desired rapid valve closure were considered. Direct actuation by a cam on the valve stem was selected because this method reduced the inertia of the valve system. The cam was cut to give smooth opening at a moderate rate and free, unchecked closing of the valve at a rate determined only by the valve weight, friction, and the spring force. Calculations showed that the valve should close in approximately 0.004 sec.

3. Mechanically, the new system worked very well. Rate of valve opening was at least as fast as before, and the valve closed in about 0.005 sec.

II. METHOD OF TESTING

A. For testing, the motor is mounted at the 40-ft radius of the rotating-boom facility, and air and gasoline are supplied to the motor, as shown in Figure 38.

B. Most tests have been made with the boom secured in a static position for convenience in adjusting the controls, and to permit observation through the underwater windows.

C. All controls and instrumentation have been mounted on the boom. The motor has been rotated for testing, when desired.

D. For both static and dynamic tests, chamber pressure is measured by a diaphragm-reluctance type of pressure pickup, and recorded on an oscillograph. A flexible section is provided in the air piping between the boom and the motor, so that thrust and drag can be measured by a variable-reluctance element coupled to an indicating meter.

E. Rate of flow of compressed air into the motor is determined by measuring the pressure drop in the air storage system during a known time interval. Since the storage volume is known, the weight of air withdrawn from the system can be computed. The rate of air consumption is small relative to the total volume, so that expansion is assumed to be isothermal. Cycling rate is determined from the oscillograph pressure records, so that the air consumption per cycle can be computed.

III. RESULTS

A. The expected increase in chamber pressure with the cam-actuated air valve was not obtained. Figure 39 shows an oscillograph record of chamber pressure taken while running with this new valve actuation system. At the point marked A, the valve has just touched its seat and the spark has passed across the electrodes of the spark plug. Combustion does not reach explosive velocity until Point B. Maximum chamber pressure due to combustion is at Point C. Approximately 0.010 sec elapses between the spark at Point A and the rapid combustion at Point B. Almost 50% of the supercharging pressure is lost during this period.

B. The motor, as it is now operating, cannot develop sufficient thrust, because the pressure rise due to combustion starts from too low a pressure. The ignition lag also results in a wasteful expansion of the compressed air during early combustion.

C. If the ignition lag were eliminated or reduced, the efficiency and power output of the motor could be much improved. This might be accomplished by any of several methods, such as multiple-ignition with more than one spark plug, or by installing a small precombustion chamber, in which early ignition could be started, so that the main charge would be ignited by the flames from the precombustion chamber. There are other possibilities, all of which would require development work.

Report No. 791

PART V

SOLID-PROPELLANT GAS-TURBINE TORPEDO POWER PLANT

I. DESCRIPTION OF WORK

A. INTRODUCTION

1. A proposed solid-propellant torpedo power plant for the EX-2 torpedo was presented to the Bureau of Ordnance in Aerojet-General Proposal PW-3205, dated 8 July 1953. The proposed unit was an extremely simple power plant as well as one that would be practical and reliable under all service operating conditions.

2. In addition, a report (Reference 5) was submitted giving more detailed information regarding the solid propellant. The proposed system and the one now being tested are composed of the same fundamental components, viz., a gas generator, a turbine and reduction gearbox, and a mechanically operated turbine speed controller. Also, an alternator and lubricating pump would be required in the torpedo installation.

B. TURBINE

1. In order that an operating power plant might be obtained in the shortest length of time and at minimum cost, components developed under other programs were utilized whenever possible. A turbine and gearbox assembly were modified to accommodate the high-pressure, high-temperature, gaseous discharge from the solid-propellant grain.

2. A 4.08-in.-dia impulse turbine wheel was modified to fit an existing bearing housing. Buckets and disk of this wheel (shown in Figure 40) were integrally cast of Haynes Stellite No. 31. Operation at a pitch line velocity of 1100 ft/sec corresponds to a wheel speed of 63,000 rpm; it is for this rpm that the power plant was designed. Utilizing a 5.75-in.-dia grain, it is expected that this power plant will deliver the required 28.3 hp (net) when operating at 1000-ft depth.

C. GAS GENERATOR

1. A simple gas generator was designed and fabricated of heavy-wall steel tubing for test-pit operation. The gas generator may be seen in Figure 41, in addition to the turbine and gearbox. Grains 6-in. long which burn approximately 60 sec were fired in this chamber. Subsequently, a similar chamber was fabricated which would accommodate grains for a full 2-min burning.

2. No particular difficulties were experienced, even though the gas generator is uncooled and operates at 2300 psi with a gas temperature of 2300°F. The grain shown in Figure 42 burns from the end in the manner of a cigarette. Restriction material 0.12 in. thick around the periphery of the grain serves to insulate the chamber walls. The end of the chamber is protected against heat loss by a layer of glass-fiber laminate covered by a carbon disk. The outlet tube and the nozzle are lined with molybdenum. This combination has functioned successfully for many runs. No erosion or nozzle enlargement has occurred.

D. IGNITER

1. An igniter previously developed for another solid-propellant unit was adapted to the torpedo engine gas generator. This igniter is one of the three-element type consisting of a black powder initiater, a mixture of Alclo and black powder, and a charge of either JPN ballistite or AN-581 propellant. This igniter has proved adequate for the present size of grain and chamber configuration.

E. SPEED REGULATOR

1. An operating torpedo power plant will require a turbine speed-regulating device which will maintain turbine rpm constant within very close limits (and consequently alternator rpm constant) for all load conditions and from operating depths varying from sea level to 1000 ft. Considerable thought has been devoted to the solution of this problem, for this device must be thoroughly reliable in order to maintain the inherently high reliability of a solid-propellant power plant.

2. In one method considered (described in Reference 6), the turbine exhaust was throttled so that a 460 psia back pressure was maintained at all times on the turbine. This has the desirable effect of making the power plant insensitive to depth, but has an adverse effect in that fuel consumption is higher than the power plant requires at all depths except maximum depth.

3. Another method of controlling turbine speed would entail a variable-area turbine nozzle which would cause pressure in the gas generator to rise when the nozzle area is reduced and decrease when the area is enlarged. Mass flow follows the same pattern, since solid propellants burn at a variable rate proportional to some power of the chamber pressure. A general formula for the burning rate of a solid propellant is

$$r = K(P_c)^n$$

where r = burning rate
K = constant
P_c = chamber pressure
n = burning rate exponent

If the burning face is of constant area, it is seen that the above relation shows mass flow to be a function of chamber pressure. A variable-area turbine nozzle is not feasible for a turbine of this size where only one nozzle of approximately 0.090-in. diameter is required. However, there is a means of control having some of the characteristics of both the methods just outlined which is practicable and which operates on the principle of a variable chamber pressure without having a variable-area turbine nozzle.

4. This may be accomplished by establishing a controlled bleed on the gas generator which vents a small amount of gas at all operating depths except maximum depth. Such a device would operate on a signal from the oil pump, whose head is a function of turbine speed. This vent lowers the gas generator pressure below the design value of 2300 psi which, in turn, lowers the burning rate of the propellant. As a result, the total operating time of the power plant is lengthened when functioning at any depth less than maximum depth. Design of such a valve is being investigated, and since the throttling principle has been employed in other Aerojet-General valves, it is expected that design details can be worked out.

II. METHOD OF TESTING

A. At the outset of this program it was evident that two fundamental types of tests would be required, viz., those utilizing the gas generator alone and those employing the full power plant installation. To avoid duplication of facilities and instrumentation, a single test pit previously used for turbine development was set up for testing the solid-propellant gas-turbine torpedo engine. Figure 43 shows the test-pit installation. At left center, the gas generator and gearbox may be seen. Below that assembly is the valve which maintains back pressure on the turbine; the large unit on the right is the dynamometer.

B. All data were recorded on a multichannel oscillograph. Included were the following variables: pressures, temper tures, turbine rpm, and horsepower. In addition, data are shown on gages in the control room which may be observed during the course of a run.

C. This solid-propellant torpedo engine was proposed as one which would operate at rated horsepower at all depths to 1000 ft. For that reason, all testing of the turbine assembly is accomplished with 1000 ft of water back pressure on the turbine exhaust. A regulating valve adjusted prior to a run maintains the exhaust pressure at the desired level. Turbine speed is regulated by the load placed on the dynamometer, so that the power recorded is that available to a propulsion system operating at 1000-ft depth.

D. The gas generator may be seen on the right in Figure 41. This is the unit designed for 60 sec operation. The chamber which houses the 12.5-in.-long grains for 2-minute tests is similar to the one pictured except for the length and is interchangeable with the short chamber. A gas generator test requires only the loading of a chamber, the installation of an igniter, and the application of a voltage to start a firing. A turbine test requires somewhat more preparation but is much simpler than most bipropellant systems.

III. RESULTS

A. PROPELLANT

1. Numerous runs have been conducted utilizing grains of the AN-2000 series of Aeroplex propellants. At the start of the program the propellant tested was designated AN-2011. Table II lists the composition and thermodynamic properties of this propellant. Two laboratory batches of this propellant were prepared for gas generator testing, but thoroughly homogeneous mixtures were not obtained, with the result that performance was not reproducible to the close tolerances deemed necessary for this propulsion system. Since laboratory batches do not have the advantage of Aerojet-General's close quality control standards applicable to production mixes, it was thought advisable to switch operations to a newer, slow-burning propellant which has evolved from the continuing propellant development by Aerojet.

2. This propellant, designated AN-2091, contains essentially the same ingredients as AN-2011, but due to changes in particle sizes and minor changes in ingredient percentages, a more homogeneous mixture has been realized. The ballistic properties of AN-2091 are essentially the same as those shown for AN-2011 in Table II. AN-2091 propellant is being prepared in production quantities at the Azusa plant and is therefore readily available for this program.

3. Several 60- and 120-sec gas generator tests were conducted utilizing AN-2091 propellant. Figure 44 shows the pressure vs time record for an 11.81-in.-long grain. Combustion was smooth throughout the run and only a relatively small pressure variation from the average pressure was noted.

B. TURBINE

An initial turbine test was conducted utilizing a 3-in.-long grain which operated smoothly for 32 sec. Since the dynamometer loading had not reached the proper balance, turbine speed was somewhat low at 51,000 rpm. No particular difficulty was encountered in operating at a chamber pressure of 2500 psi or at a 460 psia back pressure. Turbine wheel and nozzle erosion has not been a problem. A subsequent turbine test was prematurely halted due to a bearing failure in the turbine, though no serious damage occurred.

REFERENCES

1. Research, Development, and Testing of Underwater Propulsion Devices, Aerojet Report No. 675, 9 February 1953 (Confidential).

2. Research, Development, and Testing of Underwater Propulsion Devices, Aerojet Report No. 631, 12 August 1952 (Confidential).

3. Steam-Jet Condenser for Hydroductor Propulsion System, Aerojet Report No. 707, 25 May 1953 (Confidential).

4. Range Testing of the 4.5-in. Alclo Hydroduct, Aerojet Report No. L2815-9, January 1954 (Secret).

5. The Application of Aeroplex Propellant to a Torpedo of Advanced Design, Aerojet Report No. 751, 18 September 1953 (Confidential).

6. Aerojet General Proposal No. PW-3205, 8 July 1953 (Confidential).

TABLE I

RESULTS OF PRELIMINARY PERFORMANCE CALCULATIONS OF TEST STEAM GENERATOR

	Before Applying Outside Insulation	After applying Outside Insulation
Evaporation, lb/hr	485	485
Pressure of Steam at Outlet, psi	150	150
Temperature of Steam at Outlet, °F	590	555
Temperature of Feed Water, °F	60	60
Temperature of Recirculated Gas leaving Furnace, °F	2030	1930
Temperature of Recirculated Gas First Boiler, °F	1185	1035
Temperature of Recirculated Gas Second Boiler, °F	520	600
Temperature of Recirculated Gas Entering Furnace, °F	500	590
Propellant Fired, lb/hr	181	147
Ratio of Recirculated Gas to Propellant, lb/hr	7	7
Heat Balance		
Heat Fired, Btu/hr - %	811,000 - 100.0	660,000 - 100.0
Heat Absorbed, Btu/hr - %	620,000 - 76.5	612,000 - 92.6
Heat Radiation Losses, Btu/hr - %	183,650 - 22.6	43,800 - 6.7
Heat Ash and Slag Losses, Btu/hr - %	7,350 - 0.9	4,200 - 0.7
Heat Returned to Furnace, Btu/hr - %	133,500 - 16.5	141,000 - 21.4
Efficiency of Steam Generator, %	76.5	92.6

TABLE II

COMPOSITION AND THERMODYNAMIC

PROPERTIES OF AN-2011 PROPELLANT

Formulation	Wt%
Ammonium nitrate	72.79
Ammonium dichromate	1.99
Genpol A-20	9.79
Styrene	2.22
Methyl acrylate	12.22
Methyl ethyl ketone peroxide	0.49
*Cobalt octoate solution (1% Co)	0.25
*Lecithin solution	0.25

Gas Composition

(at adiabatic flame temperature)

	mol%	wt%
H_2	22.43	2.27
H_2O	33.33	30.23
CO	16.67	23.45
CO_2	8.64	17.40
N_2	18.93	26.65

Auto-ignition temperature, °F	360
Density of solid propellant, lb/in.^{3}	0.053

Thermodynamic Properties

	Pressure, psia	
Theoretical specific impulse,	1000	2000
I_{sp}, lb-sec/lb	191	200

Experimental flame temperature, °F	2320
Theoretical flame temperature, °F	2320
Molecular weight of gases, M	20.4
Effective k (c_p/c_v)	1.28
Theoretical C_w, lb/sec-lb	0.00825
Experimental C_w, lb/sec-lb	0.00825

*10% in styrene

C-4151 12-23-52 BK EGL

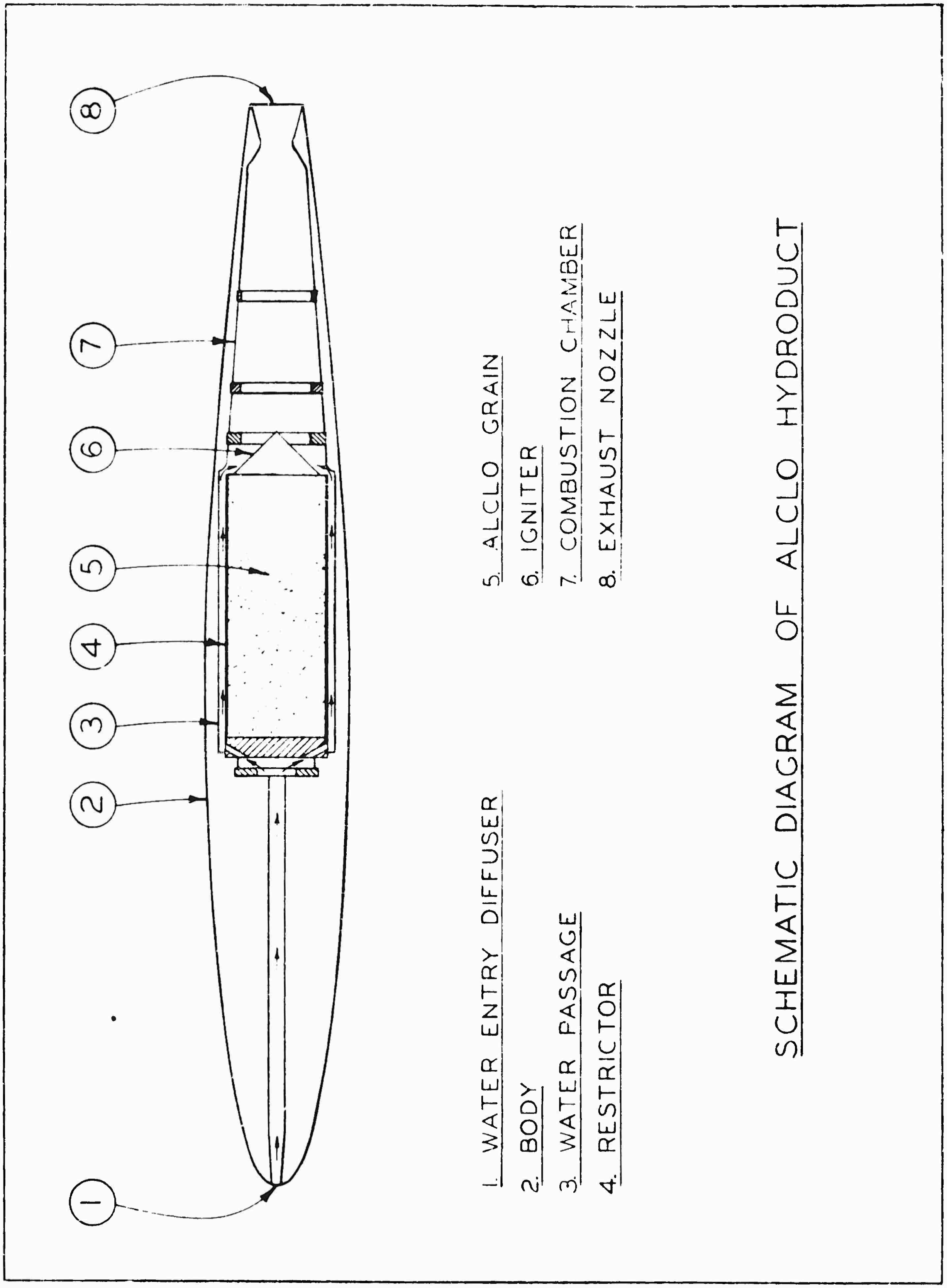
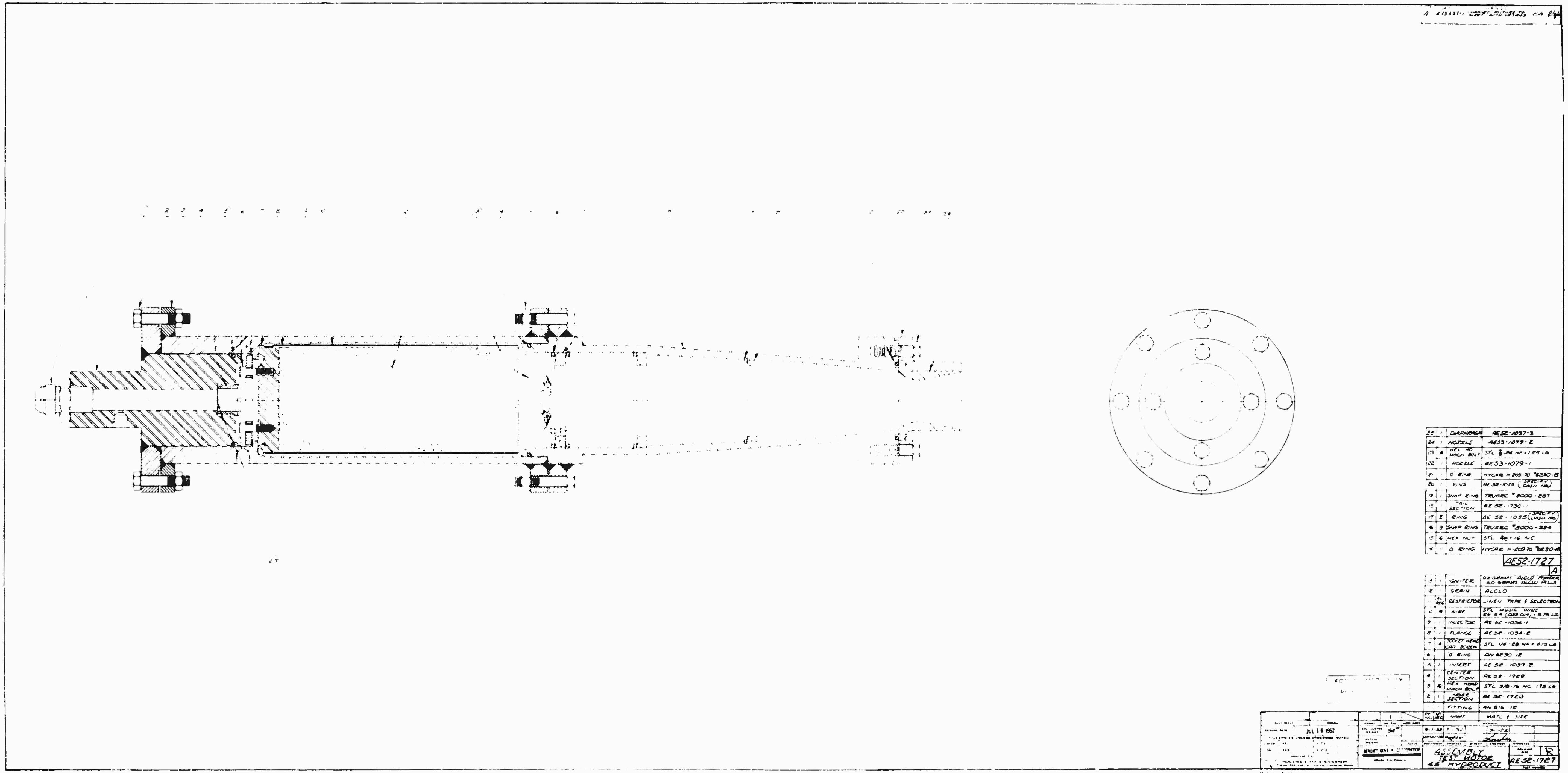
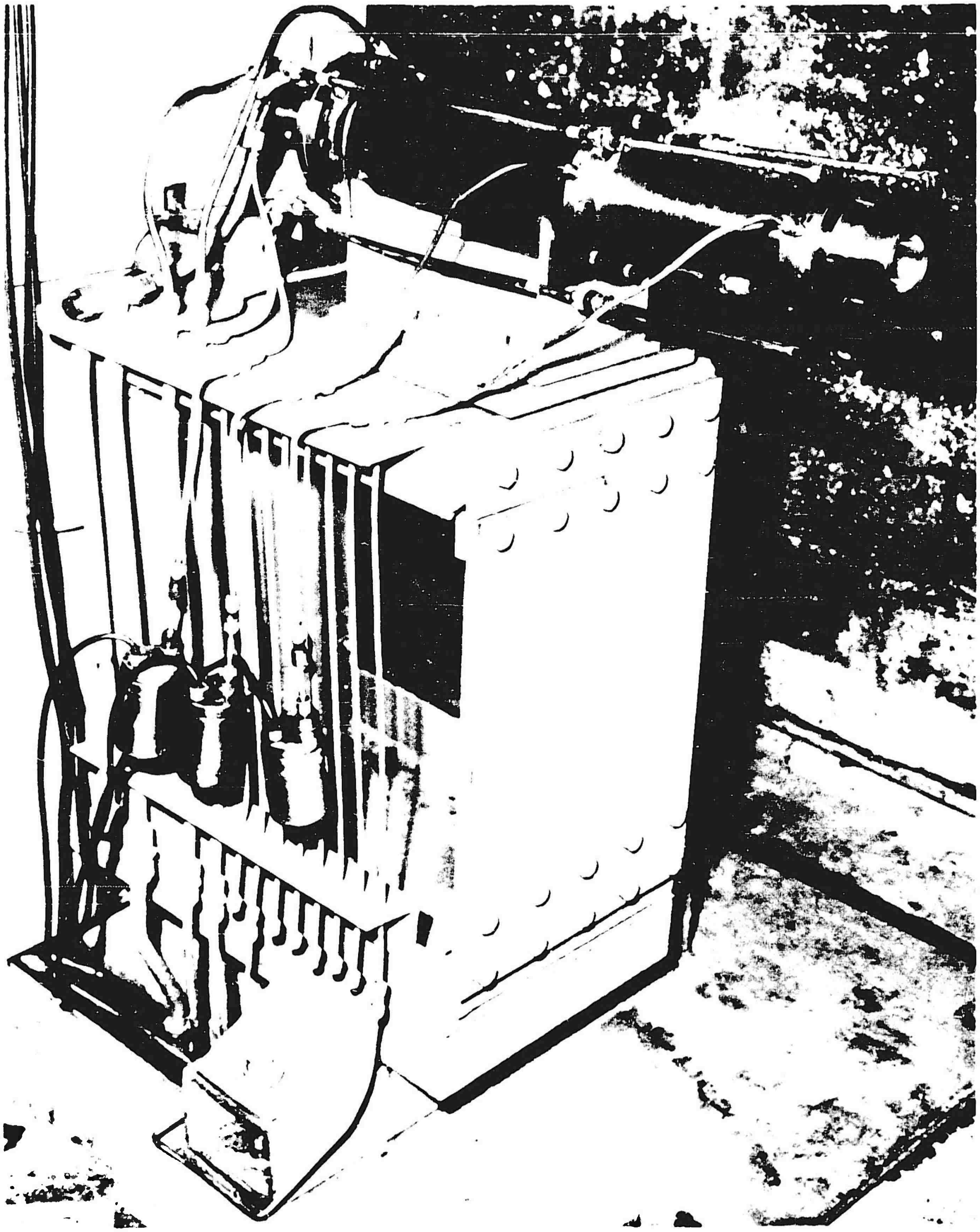


Figure 1



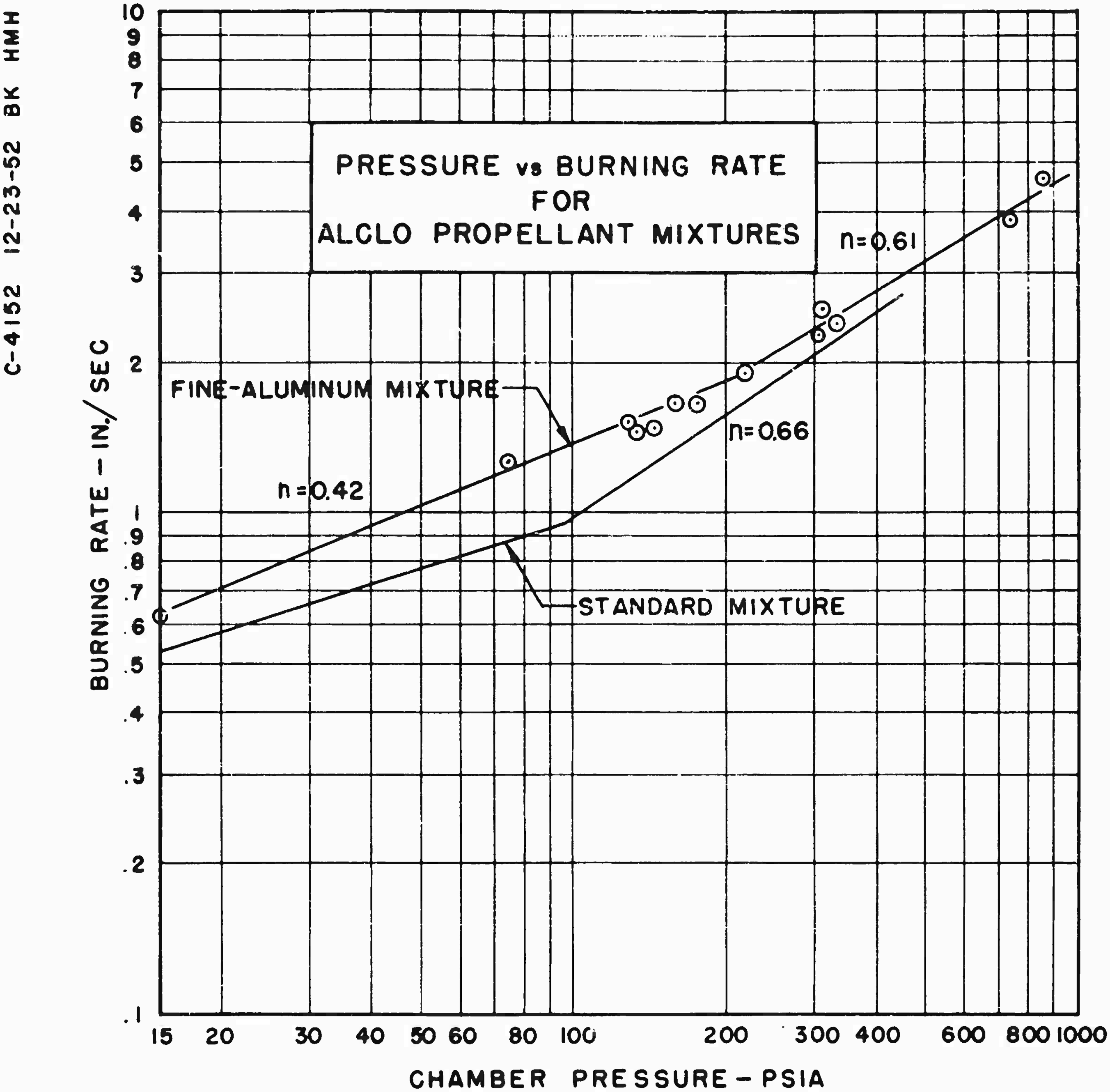
25 1 DIAPHRAGM AE52-1037-3
24 1 NOZZLE AE53-1079-2
23 4 HEX HD MACH BOLT STL 3/8-24 NF x 1.25 LG
22 1 NOZZLE AE53-1079-1
21 1 O RING HYCAR H-209-70 #6230-8
20 1 RING AE52-1035 (SPECIFY DASH NO)
19 1 SNAP RING TRUARC #5000-287
18 1 TAIL SECTION AE52-1730-1
17 2 RING AE52-1035 (SPECIFY DASH NO)
16 3 SNAP RING TRUARC #5000-334
15 6 HEX NUT STL 3/4-16 NC
14 1 O RING HYCAR H-209-70 #6230-16
AE52-1727
A
1 IGNITER 0.2 GRAMS ALCLO POWDER 6.0 GRAMS ALCLO PILLS
2 GRAIN ALCLO
AS REQ RESTRICTOR LINEN TAPE & SELECTRON
6 WIRE STL MUSIC WIRE 26 GA (.059 DIA) x 8.75 LG
9 1 INJECTOR AE52-1034-1
8 1 FLANGE AE52-1034-2
7 4 SOCKET HEAD CAP SCREW STL 1/4-28 NF x .875 LG
6 'O' RING AN 6230-12
5 1 INSERT AE52-1037-2
4 1 CENTER SECTION AE52-1729
3 16 HEX HEAD MACH BOLT STL 3/8-16 NC 1.75 LG
2 1 NOSE SECTION AE52-1723
FITTING AN 816-12
IT NO. NO. REQ NAME MATL & SIZE
JUL 16 1952
ASSEMBLY TEST MOTOR 4.5" HYDRODUCT
R
AE52-1727

Figure 2



Alclo Motor Setup for Testing in Static Test Pit

Figure 3



FINE-ALUMINUM MIXTURE

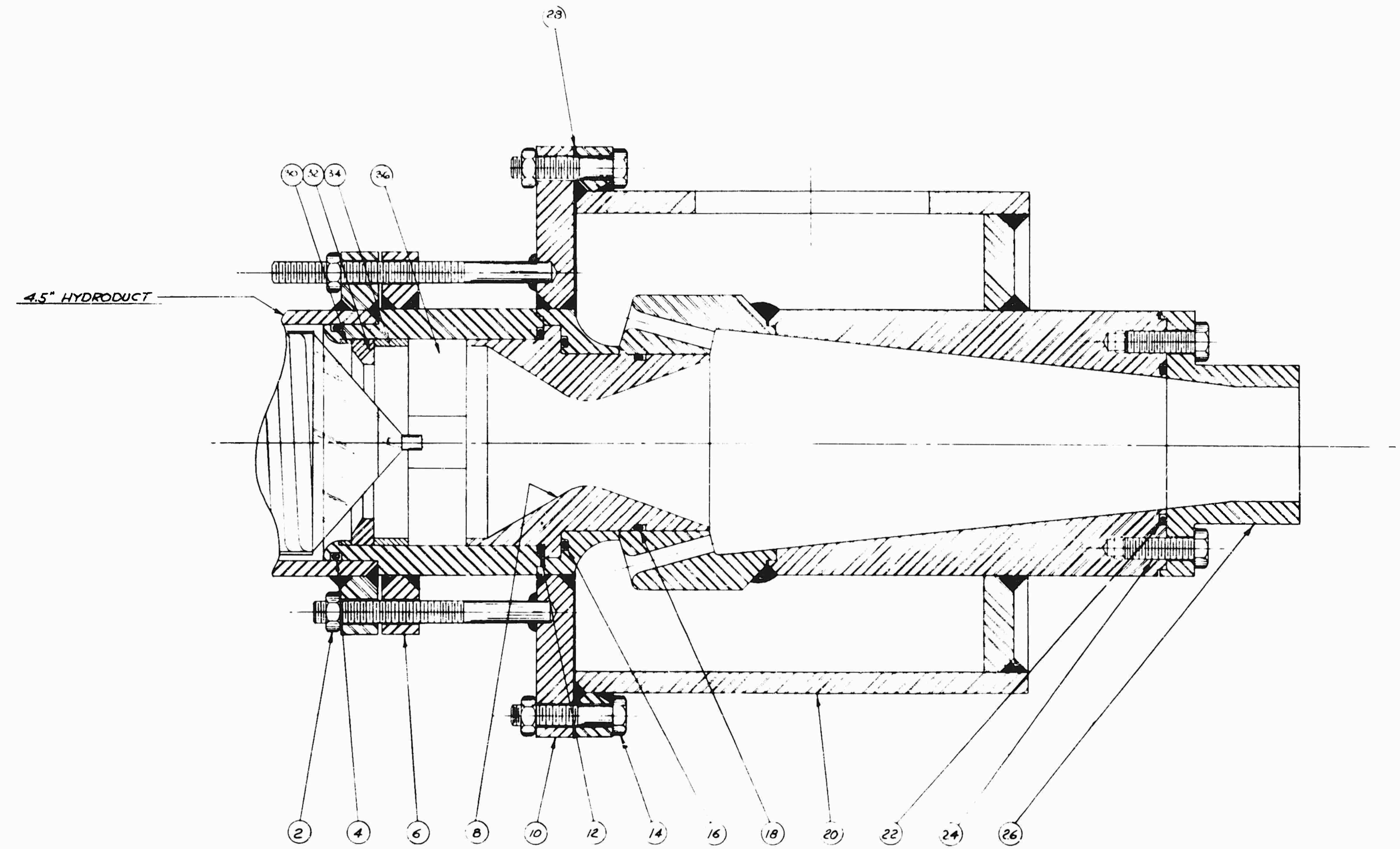
AL #552	31.4 %
KCLO4	55.8 %
Pb	12.8 %

STANDARD MIXTURE

AL #606	31.4 %
KCLO4	55.8 %
Pb	12.8 %

Figure 4

LETTER	DATE	CHANGE	BY	CHK'D
A	12-16-53	ADDED -30, -32, -34, -36	R.SPIES	



36	1	CROSS 0-000472
34	1	SPACER 0-000471-4

S-12622 (A)

PART NO	NO. REQD	DESCRIPTION
32	1	RING S-12256
30	1	SPACER 0-000471-2
28	AS REQD	GASKET ASBESTOS SHT 1/8" THK. GARLOCK OR NO. 7228
26	1	EXIT NOZZLE TEST MODEL 4.5 S-12220
24	4	BOLT - AN60-6-10
22	1	O RING - AN6230-8
20	1	CONDENSING SECTION TEST MODEL S-12218
18	1	O RING - AN6230-10
16	1	O RING - AN6230-15
14	16	BOLT - AN65-6-20
12	1	O RING - AN6230-[illegible]-16
-10	1	NOZZLE FLANGE TEST MODEL 4.5 S-12621
-8	1	REPLACEABLE NOZZLE 0-00[illegible]
-6	1	CHAMBER AE52-2390-1
-4	1	O RING AN6230-18
-2	24	NUT AN335-6

FOR RECORD ONLY
DO NOT FABRICATE
TO THE PRINT

TO BE USED WITH AE52-1727

NOTE: THIS DRAWING MUST NOT LEAVE THE PLANT AND PART MUST BE FABRICATED IN AEROJET SHOPS.

NOTES: 1. Remove all burrs and sharp edges

HEAT TREAT		FINISH	
RELEASE DATE	APR 6 1953		
TOLERANCES UNLESS OTHERWISE NOTED			
LINEAR	XX	±.03	
TOL.	XXX	±.010	
ANGULAR TOL.			

123 INDICATES SURFACE ROUGHNESS

W.O. 2806 — MODEL 1 — NEXT ASSY.

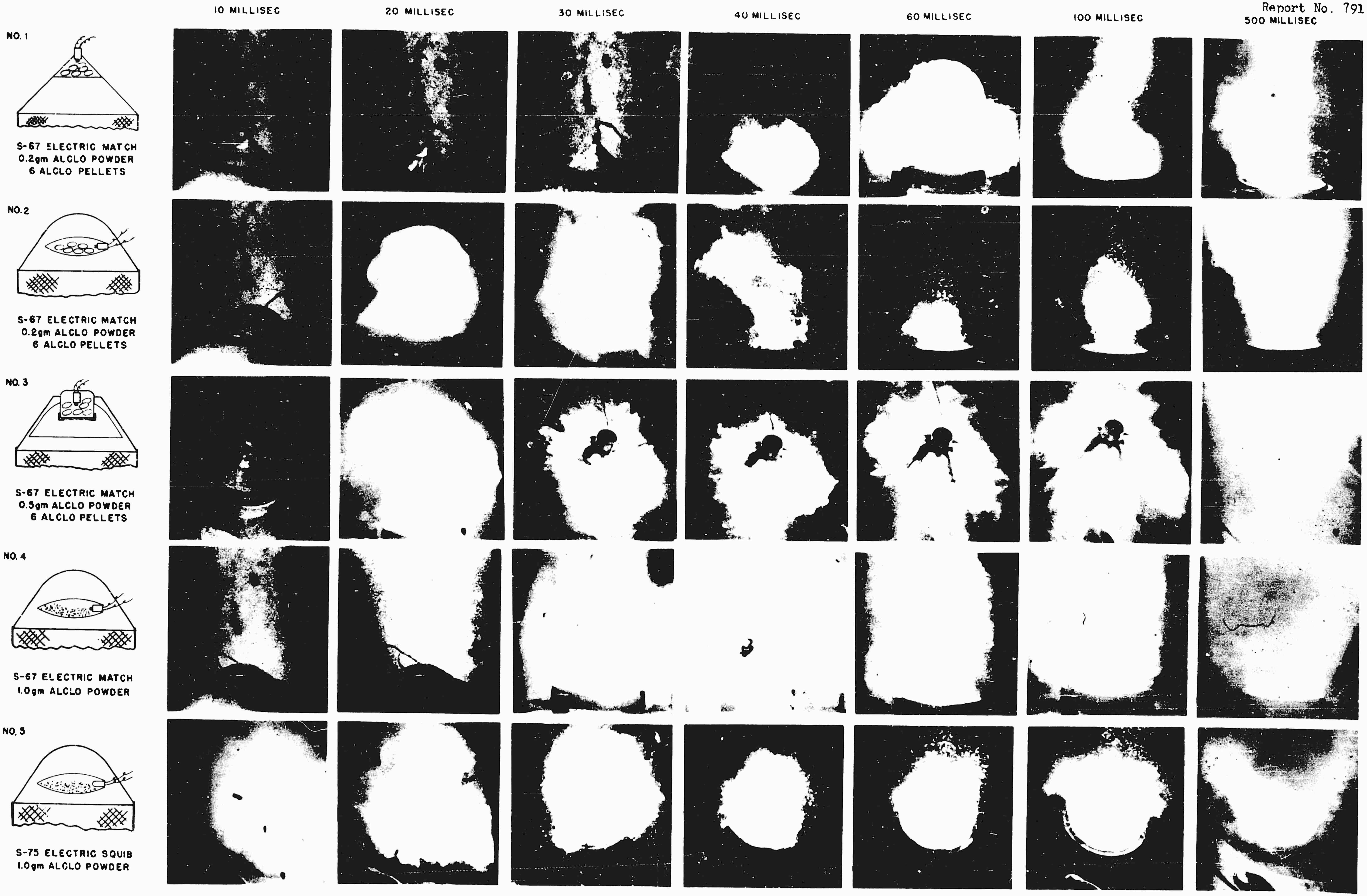
CALCULATED WEIGHT — ACTUAL WEIGHT — SCALE: FULL

AEROJET GENERAL CORPORATION, AZUSA, CALIFORNIA

DRAFTSMAN	CHECKED	STRESS	ENGINEER	APPROVED
3-23-53 ADAMS	4-2-53 Kelske		4-2-53 Spies	

ASSEMBLY - TEST MODEL 4.5" — D — S-12622

Figure 5



A Composite of Alclo Igniter Tests Taken From High-Speed Motion Pictures

Figure 6

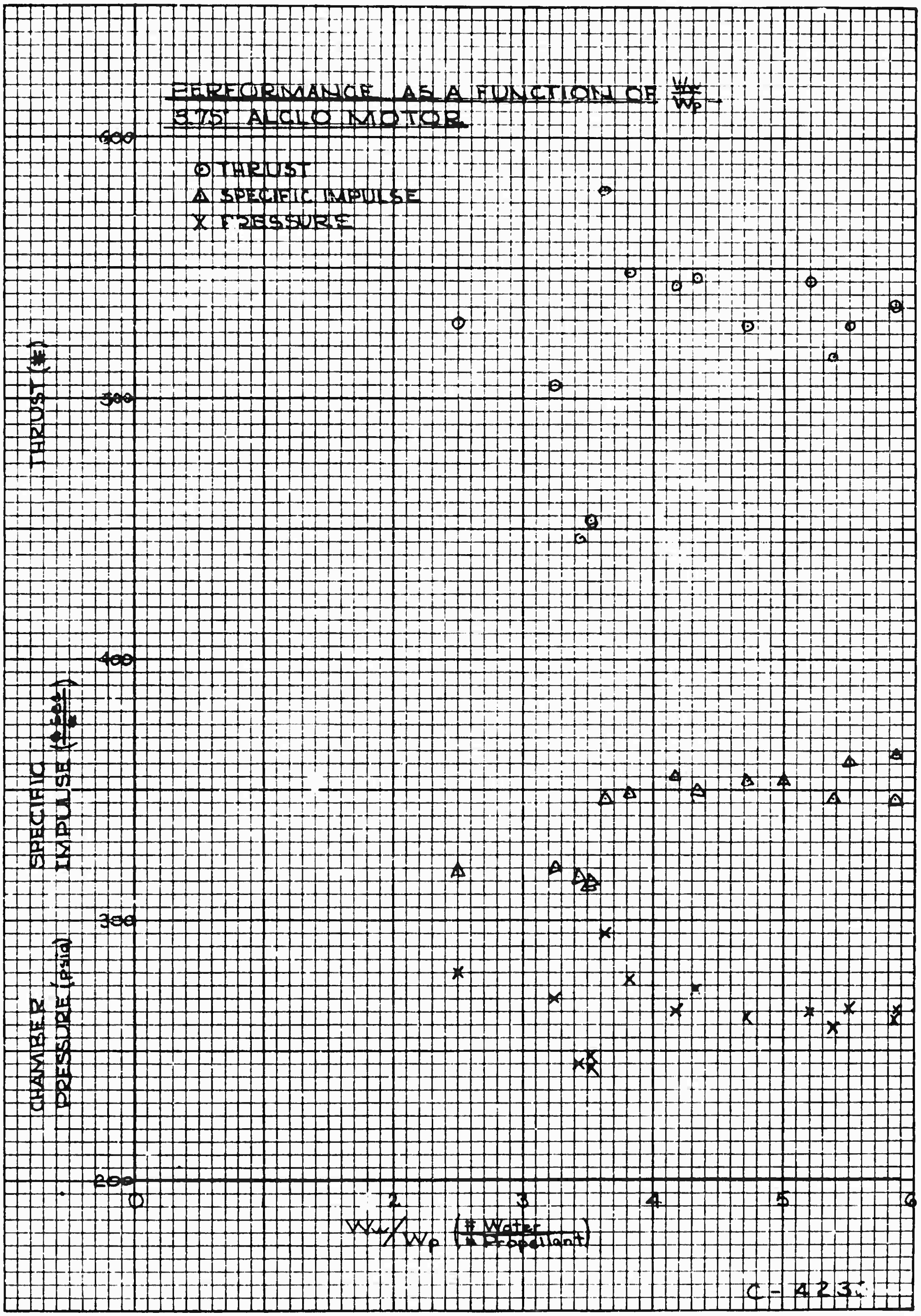
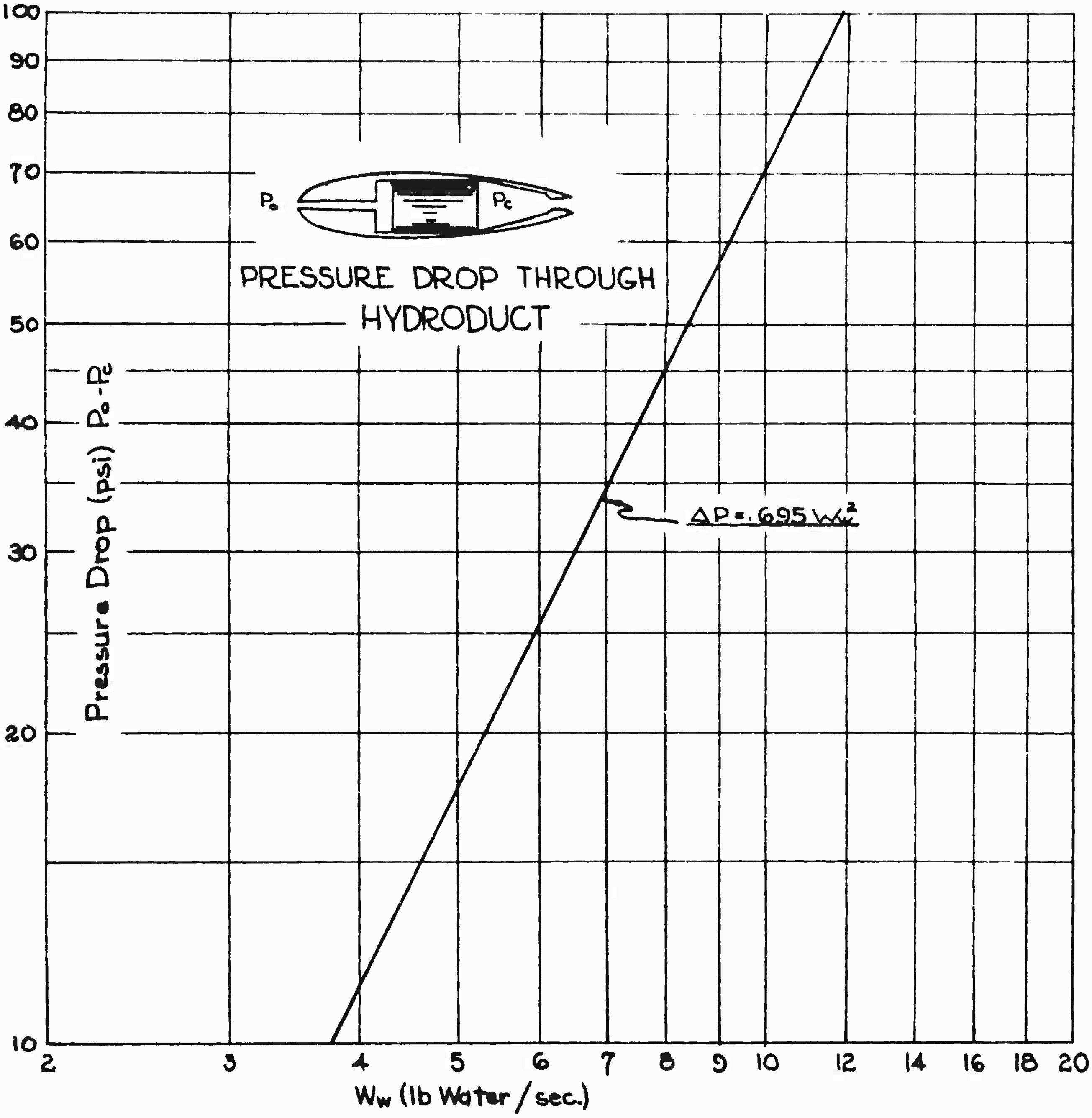

PERFORMANCE AS A FUNCTION OF $\frac{W_w}{W_p}$
3.75" ALCLO MOTOR
⊙ THRUST
△ SPECIFIC IMPULSE
X PRESSURE
THRUST (#)
SPECIFIC IMPULSE (#-sec/#)
CHAMBER PRESSURE (psia)
600
500
400
300
200
0
2
3
4
5
6
W_w/W_p (# Water / # Propellant)
C-423

Figure 7



C-4234

Figure 8

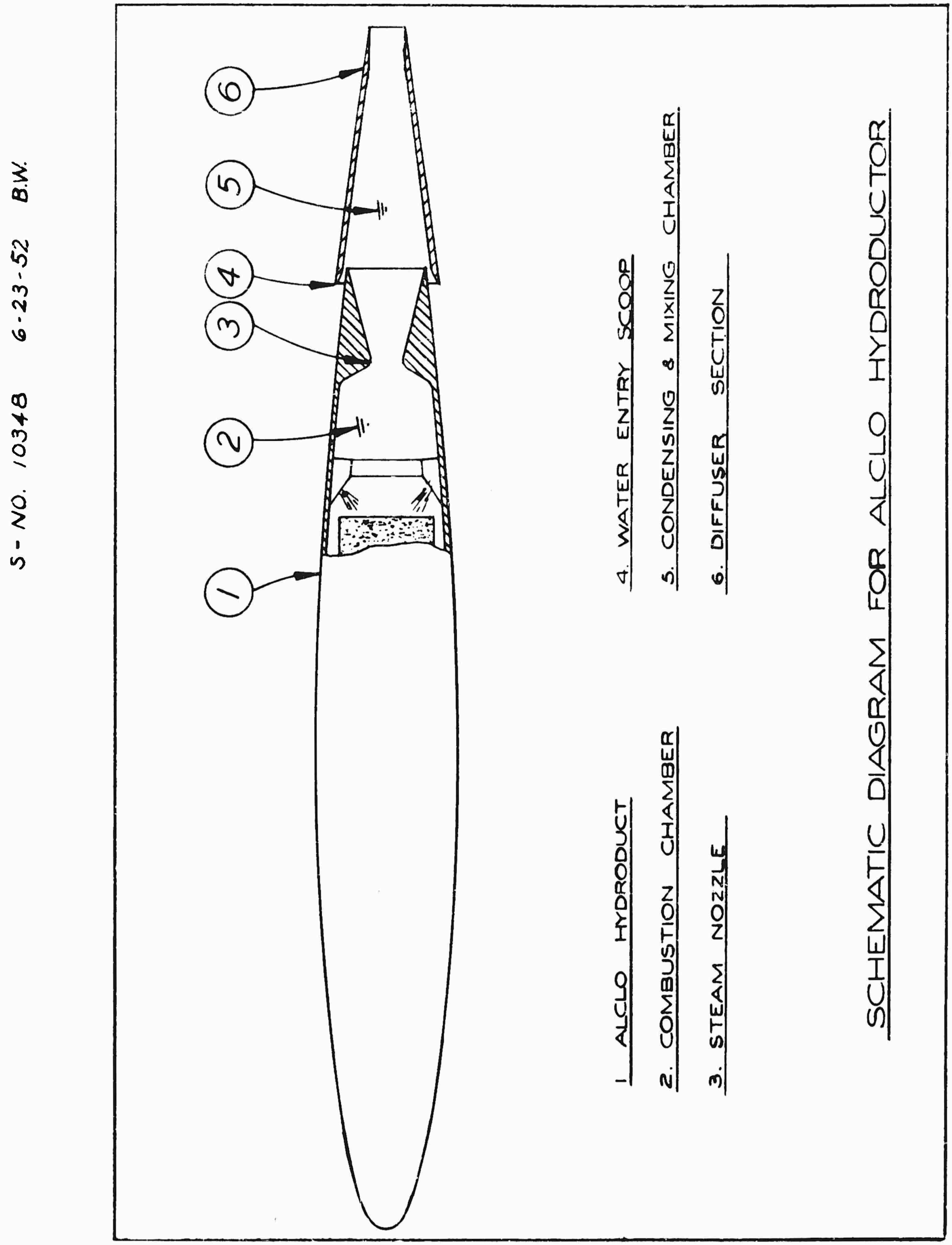
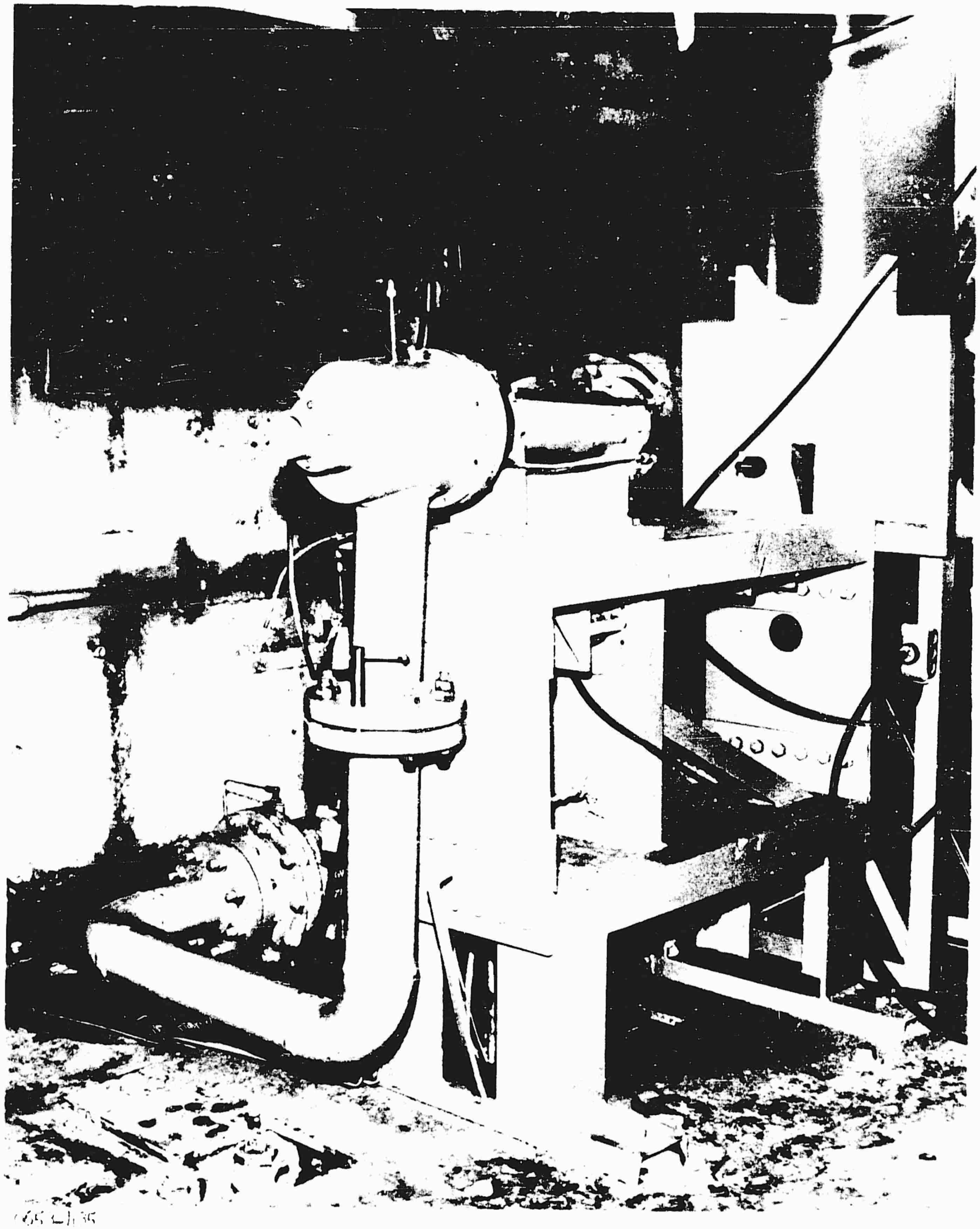

S-NO. 10348 6-23-52 B.W.
1
2
3
4
5
6
1. ALCLO HYDRODUCT
2. COMBUSTION CHAMBER
3. STEAM NOZZLE
4. WATER ENTRY SCOOP
5. CONDENSING & MIXING CHAMBER
6. DIFFUSER SECTION
SCHEMATIC DIAGRAM FOR ALCLO HYDRODUCTOR

Figure 9



Hydroductor Test-Pit Setup

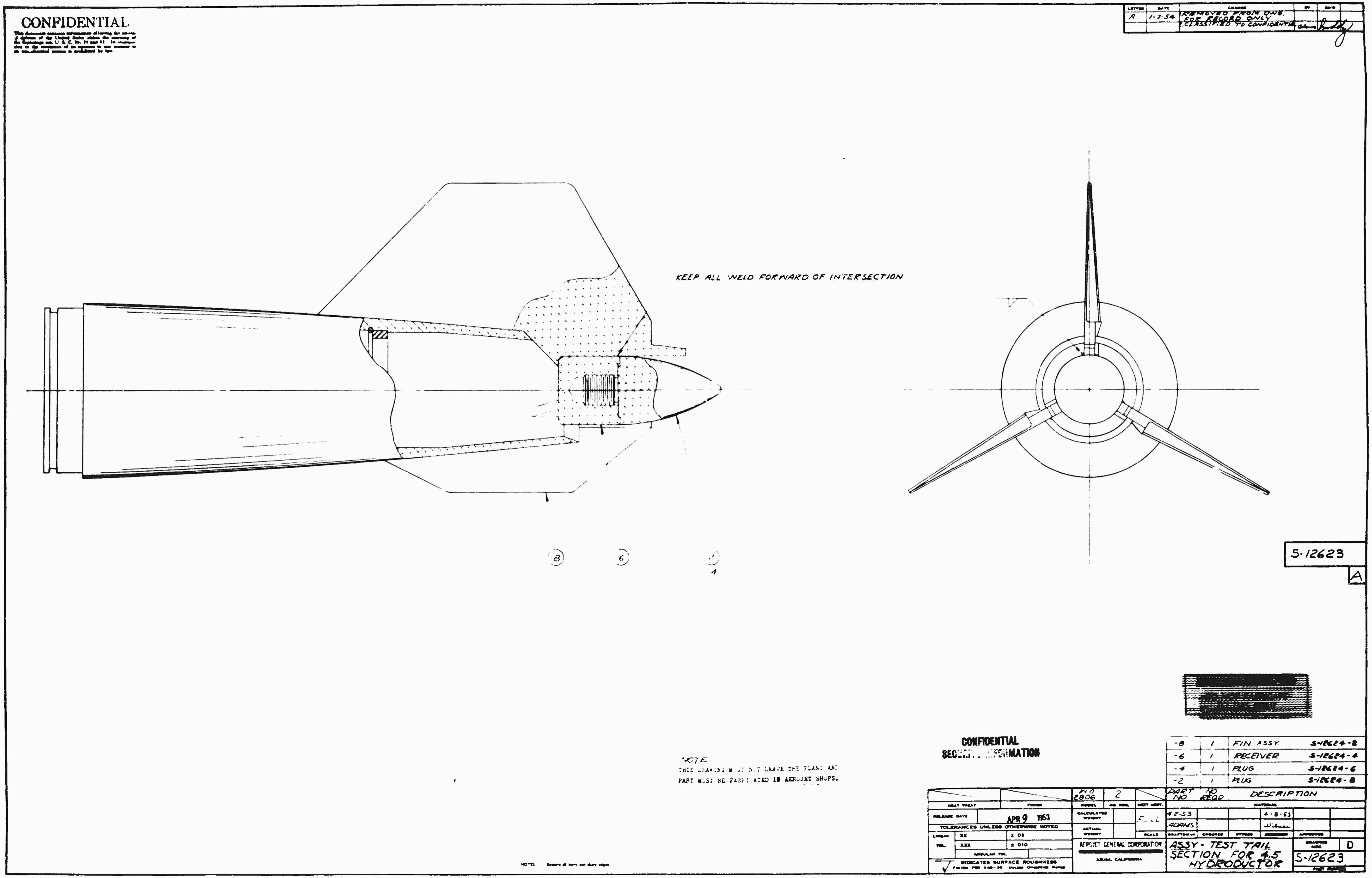
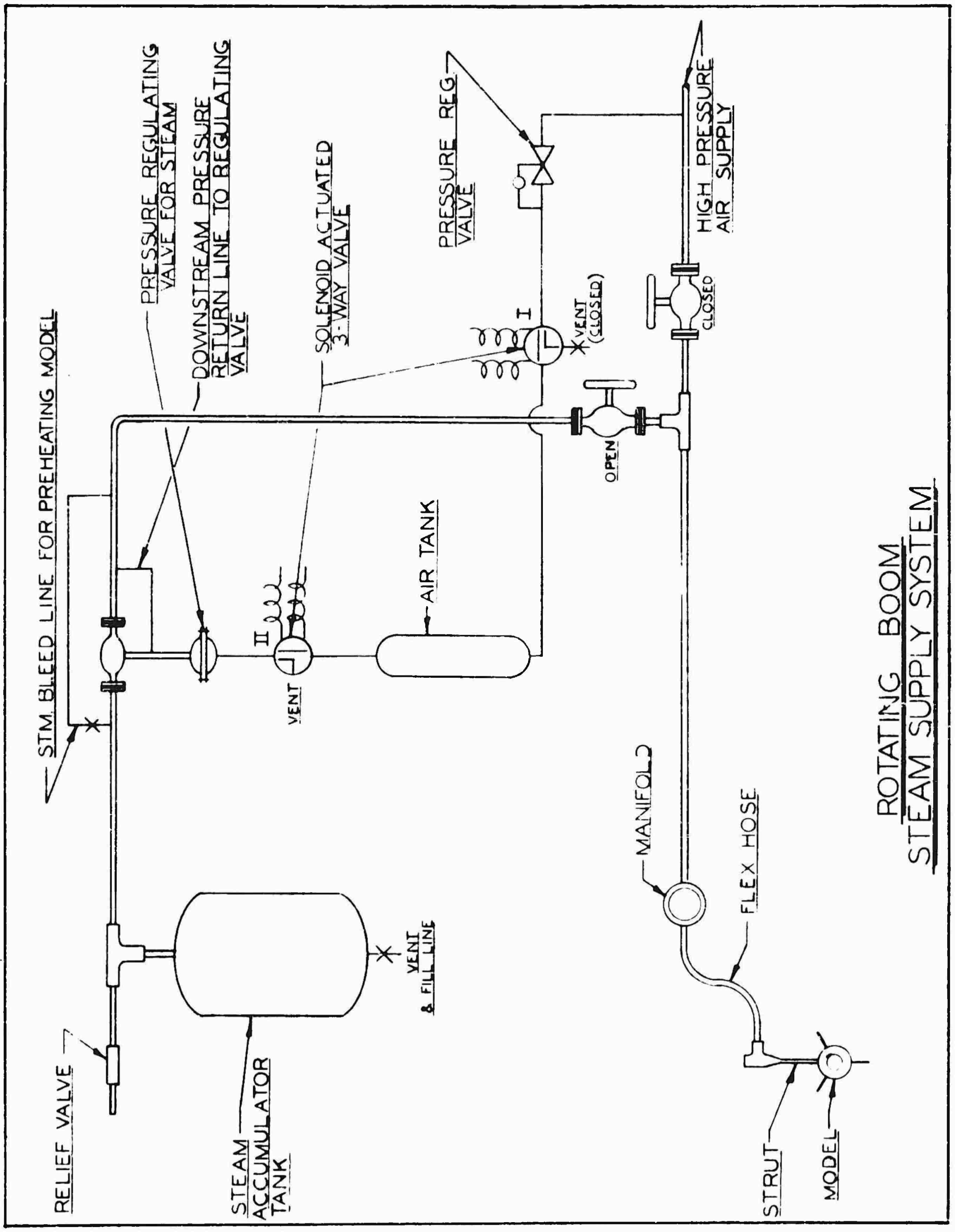

CONFIDENTIAL
A 1-7-54 REMOVED FROM DWG. FOR RECORD ONLY. CLASSIFIED TO CONFIDENTIAL
KEEP ALL WELD FORWARD OF INTERSECTION
8
6
4
S-12623
A
[redacted]
CONFIDENTIAL
SECURITY INFORMATION
NOTE
THIS DRAWING MUST NOT LEAVE THE PLANT AND
PART MUST BE FABRICATED IN AEROJET SHOPS.
-8 1 FIN ASSY. S-12624-8
-6 1 RECEIVER S-12624-4
-4 1 PLUG S-12624-6
-2 1 PLUG S-12624-8
PART NO NO REQD DESCRIPTION
W.O 2806 2
APR 9 1953
TOLERANCES UNLESS OTHERWISE NOTED
XX ± .03
XXX ± .010
INDICATES SURFACE ROUGHNESS
4-2-53 ADAMS
4-8-53
AEROJET GENERAL CORPORATION
AZUSA, CALIFORNIA
ASSY - TEST TAIL SECTION FOR 4.5 HYDRODUCTOR
D
S-12623

Figure 11



C-4236

Figure 12

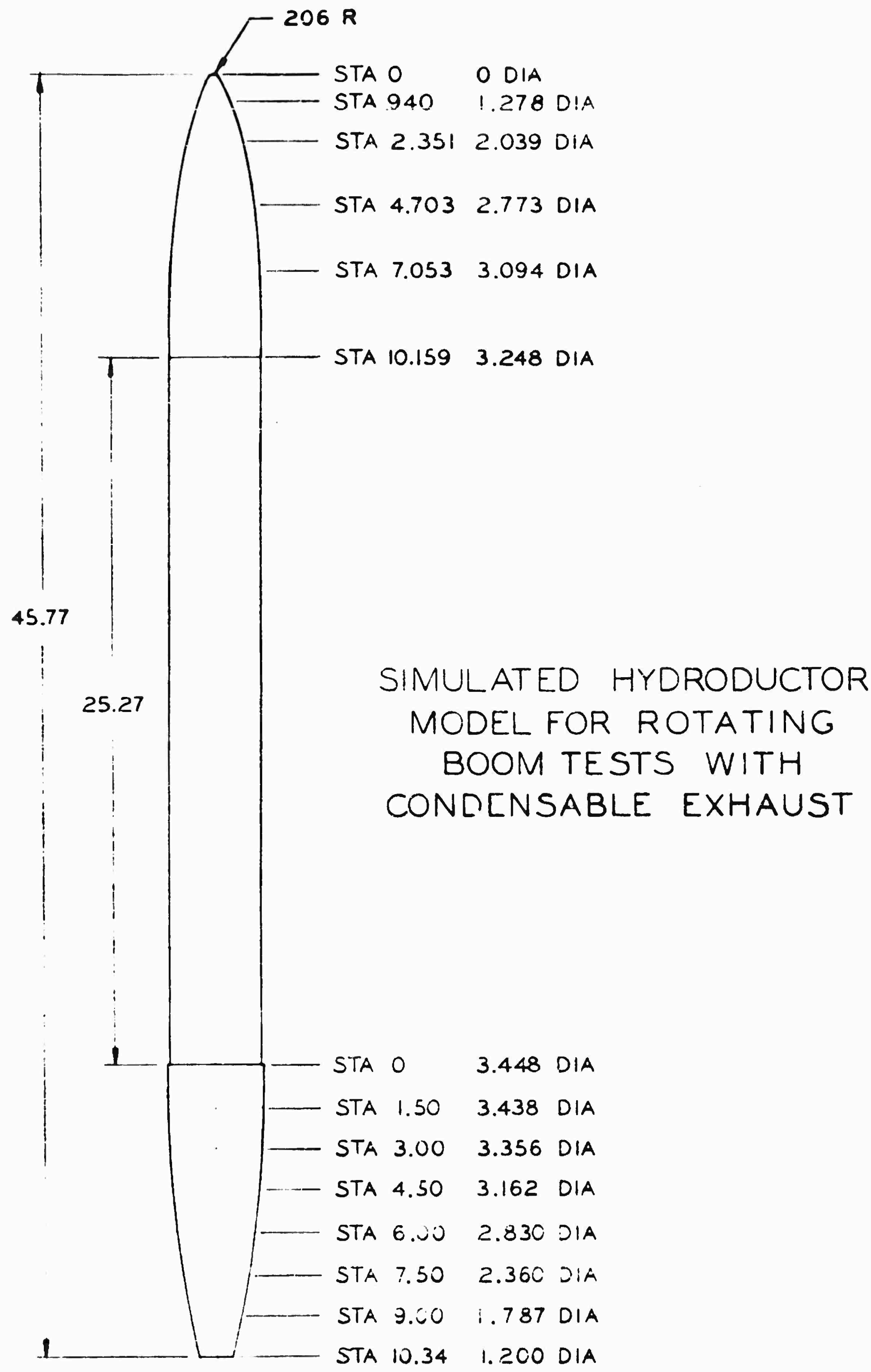
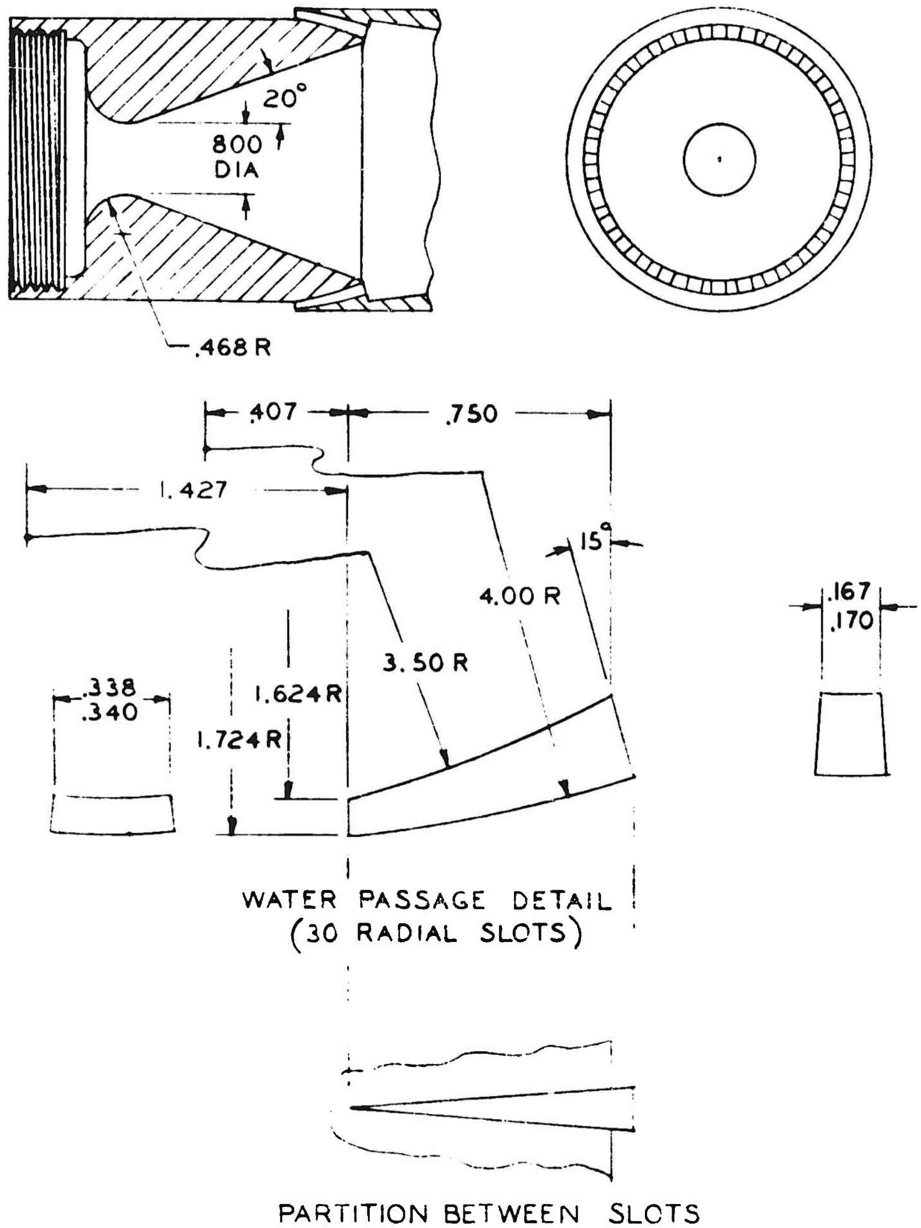
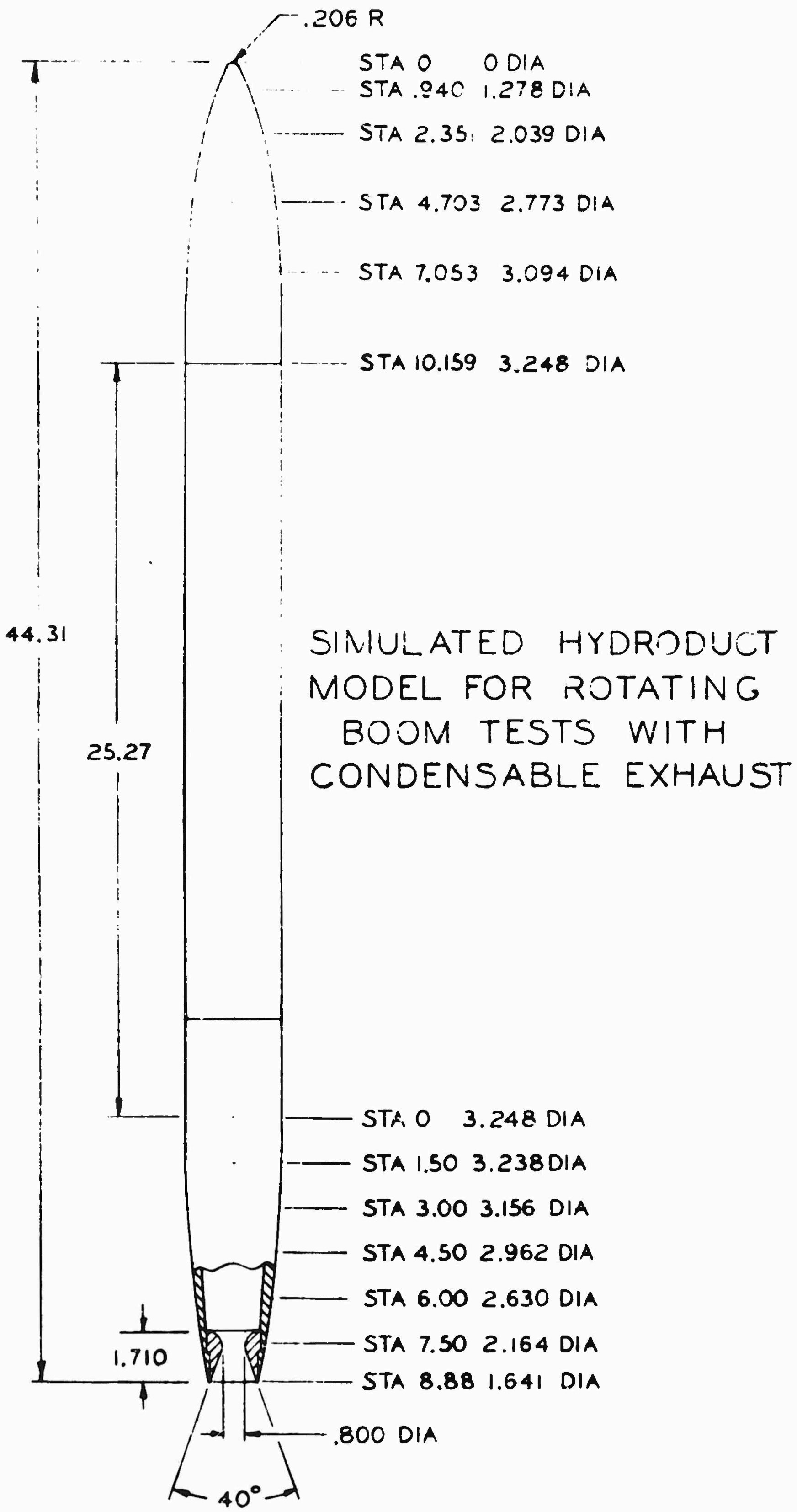

206 R
STA 0 0 DIA
STA .940 1.278 DIA
STA 2.351 2.039 DIA
STA 4.703 2.773 DIA
STA 7.053 3.094 DIA
STA 10.159 3.248 DIA
45.77
25.27
SIMULATED HYDRODUCTOR
MODEL FOR ROTATING
BOOM TESTS WITH
CONDENSABLE EXHAUST
STA 0 3.448 DIA
STA 1.50 3.438 DIA
STA 3.00 3.356 DIA
STA 4.50 3.162 DIA
STA 6.00 2.830 DIA
STA 7.50 2.360 DIA
STA 9.00 1.787 DIA
STA 10.34 1.200 DIA

Figure 13

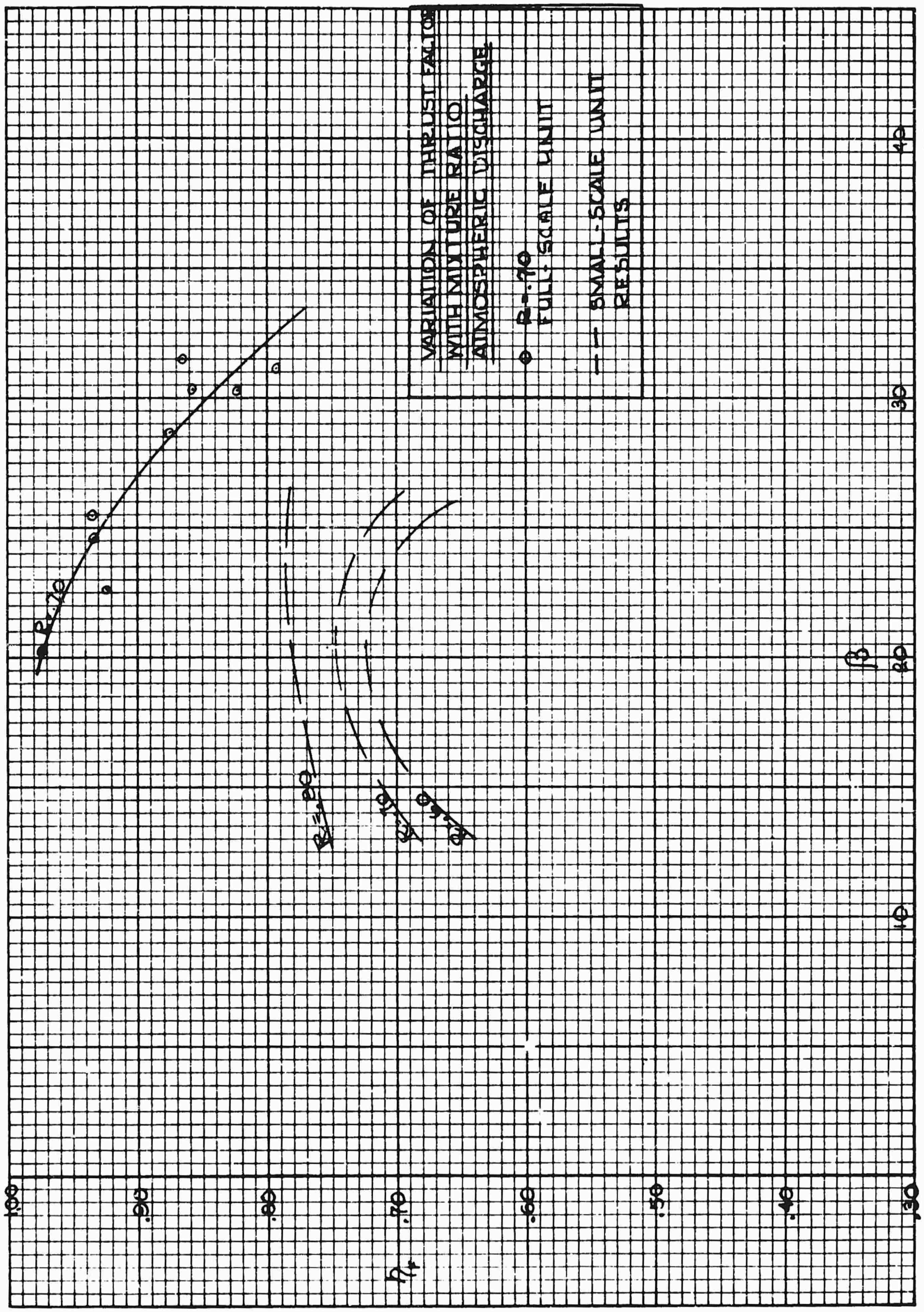


HYDRODUCTOR STEAM NOZZLE
AND SCOOP PASSAGE DETAILS



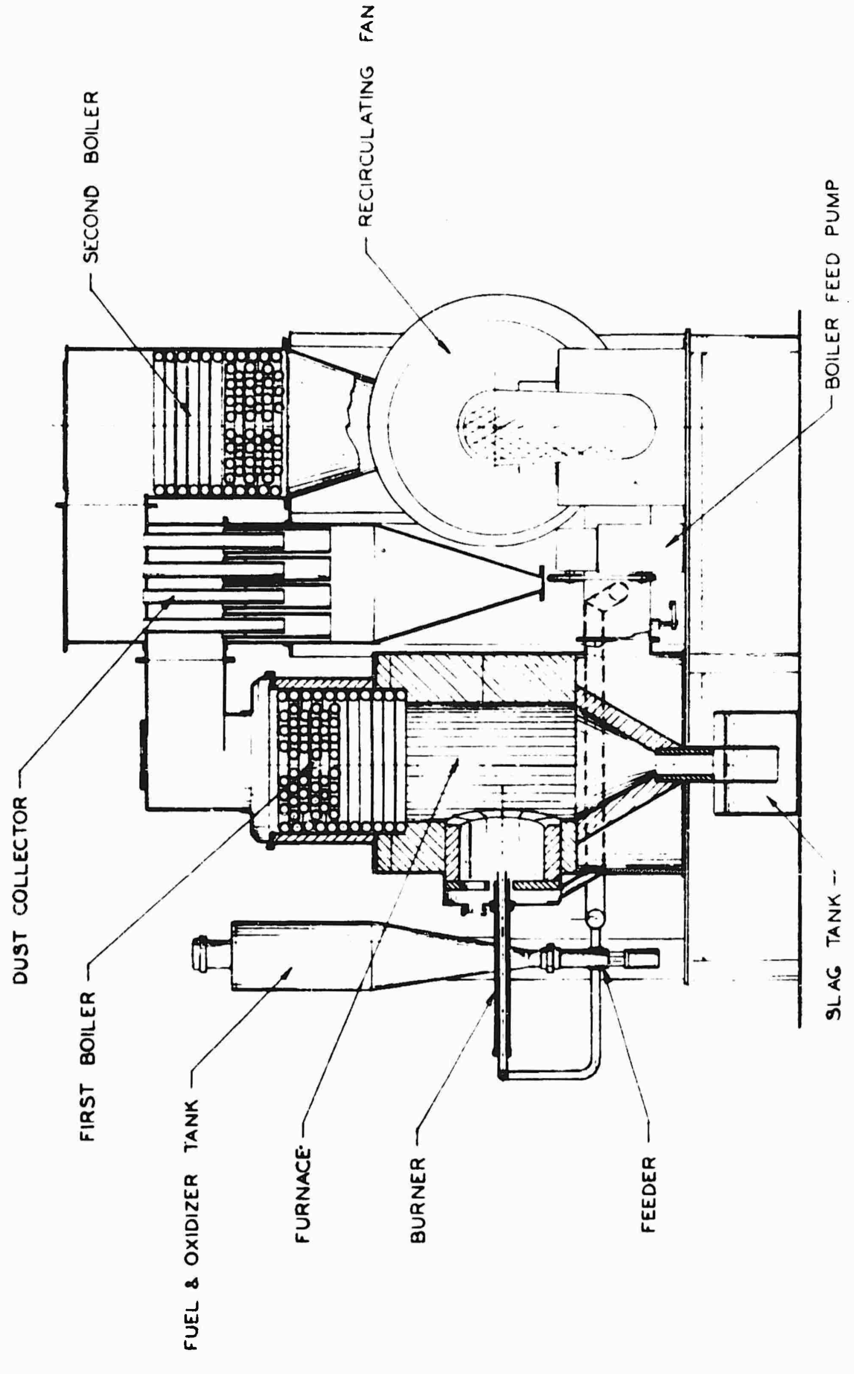
.206 R
STA 0 0 DIA
STA .940 1.278 DIA
STA 2.351 2.039 DIA
STA 4.703 2.773 DIA
STA 7.053 3.094 DIA
STA 10.159 3.248 DIA
44.31
25.27
SIMULATED HYDRODUCT MODEL FOR ROTATING BOOM TESTS WITH CONDENSABLE EXHAUST
STA 0 3.248 DIA
STA 1.50 3.238 DIA
STA 3.00 3.156 DIA
STA 4.50 2.962 DIA
STA 6.00 2.630 DIA
STA 7.50 2.164 DIA
STA 8.88 1.641 DIA
1.710
.800 DIA
40°

Figure 15



C-4235

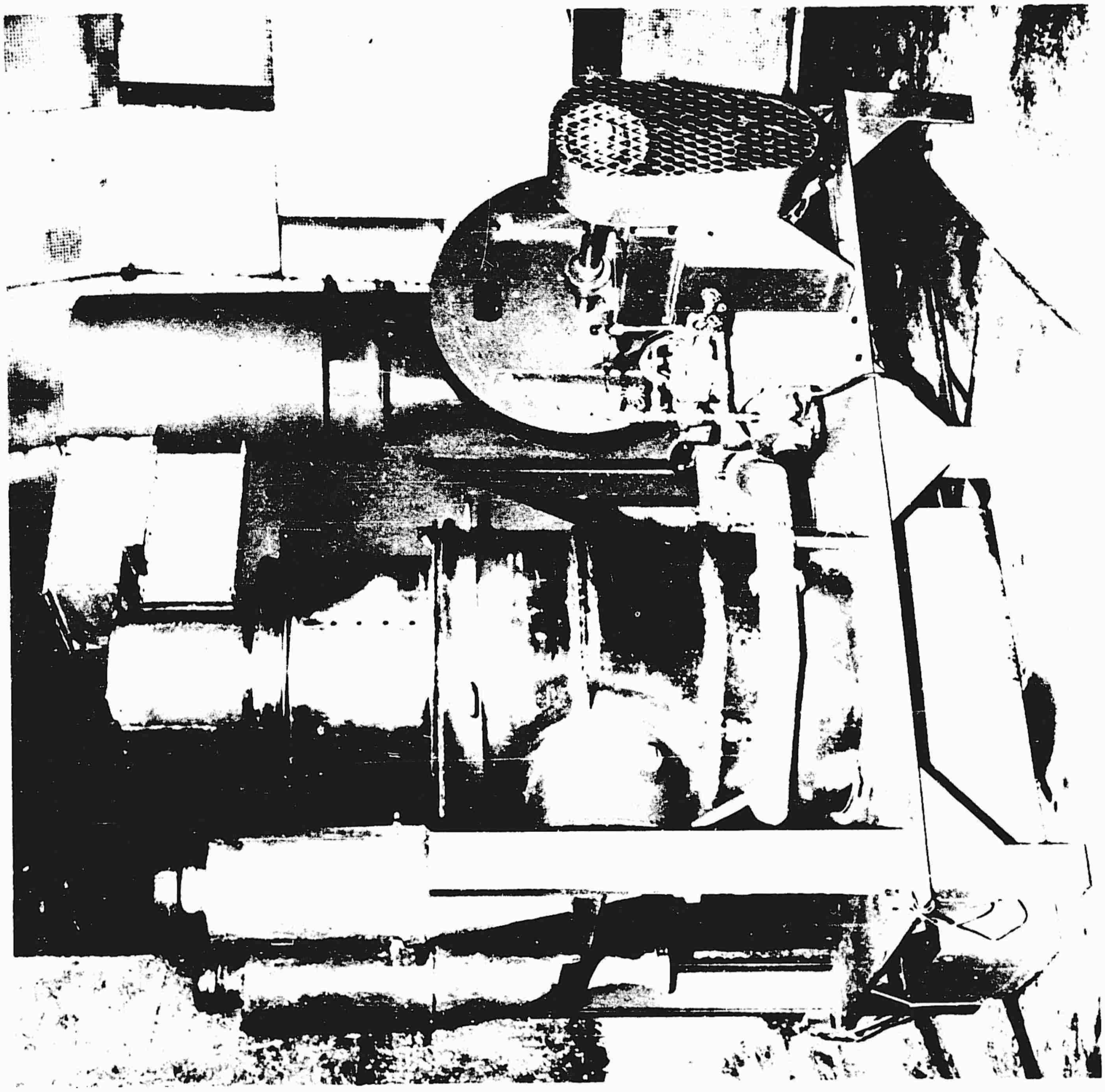
Figure 16



CLOSED CYCLE
TEST STEAM GENERATOR

C-4226 9-18-52 MB

Figure 17



Test Steam Generator

Figure 18

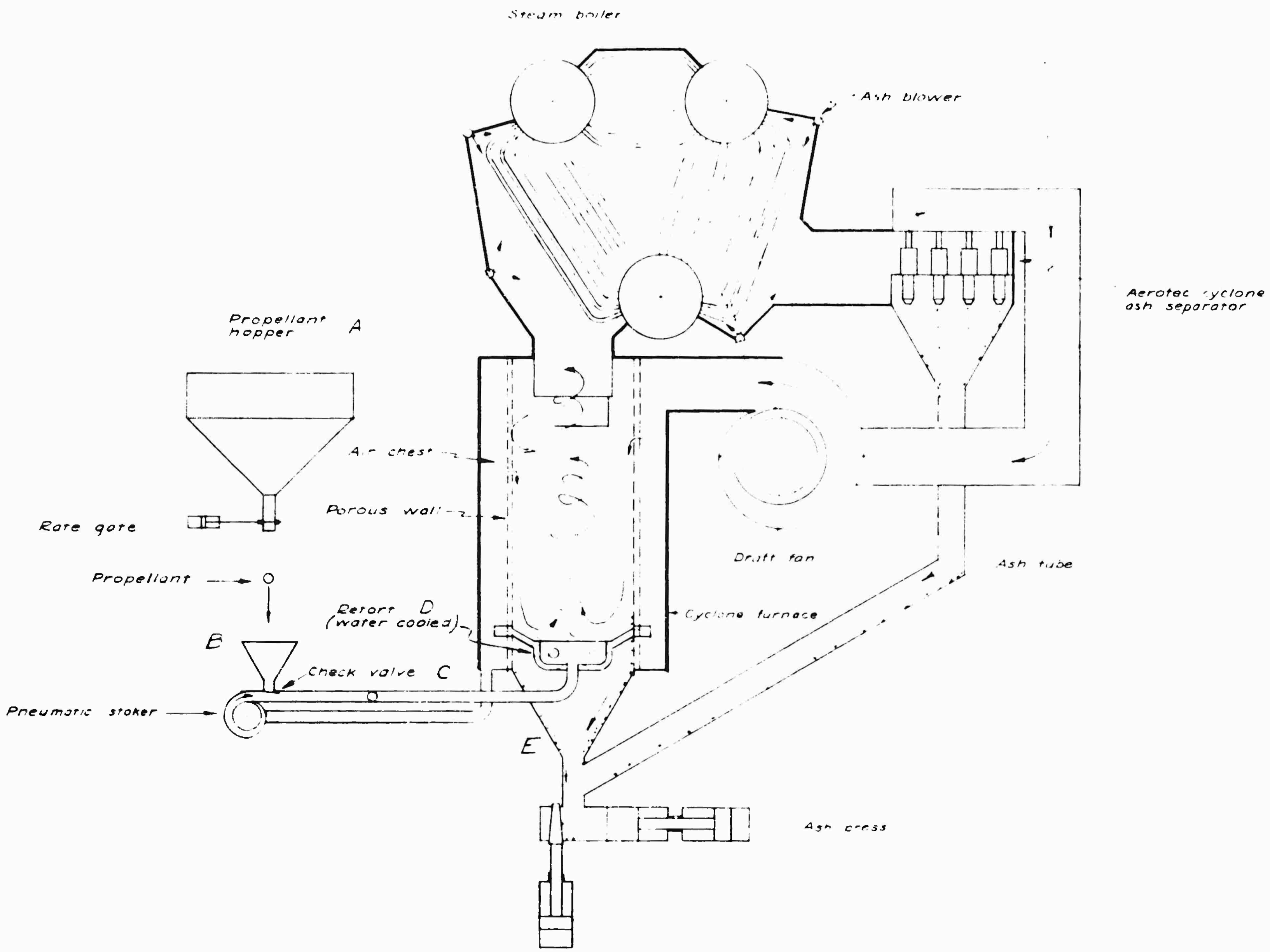
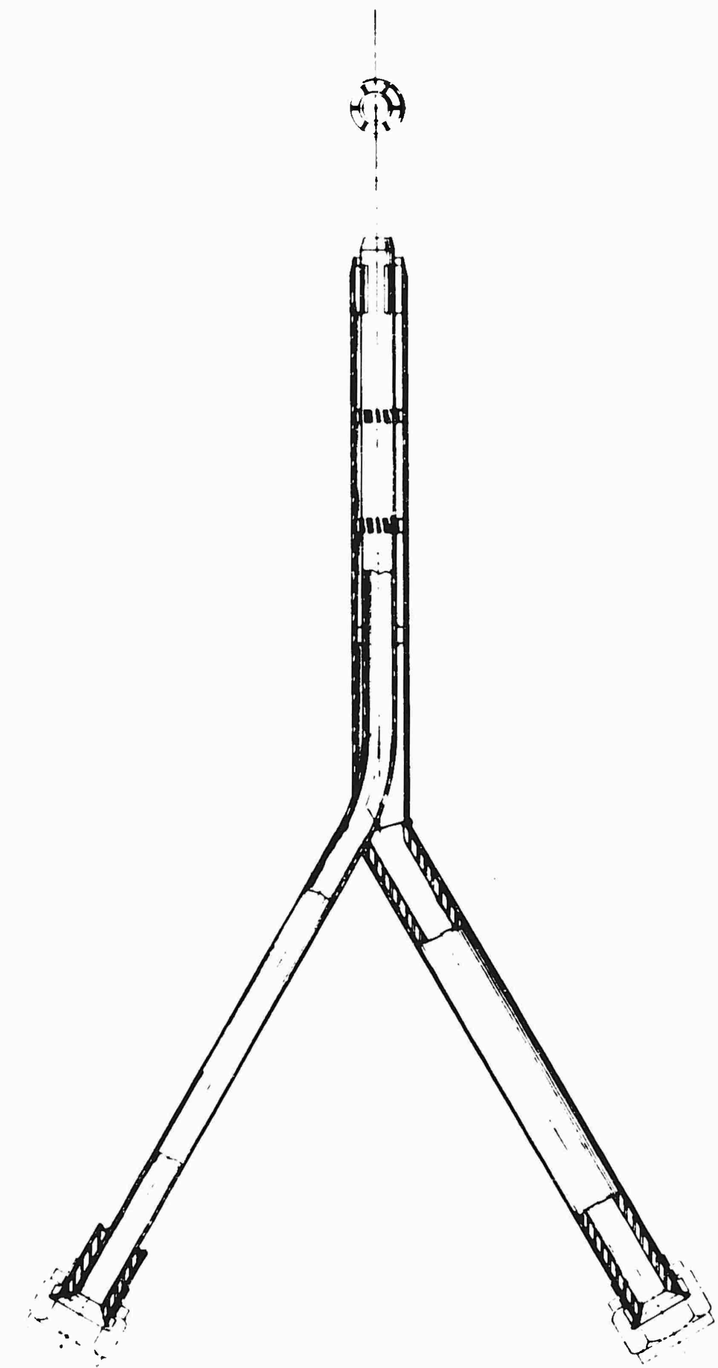


Diagram of an Alclo-Fueled Submarine Power Plant

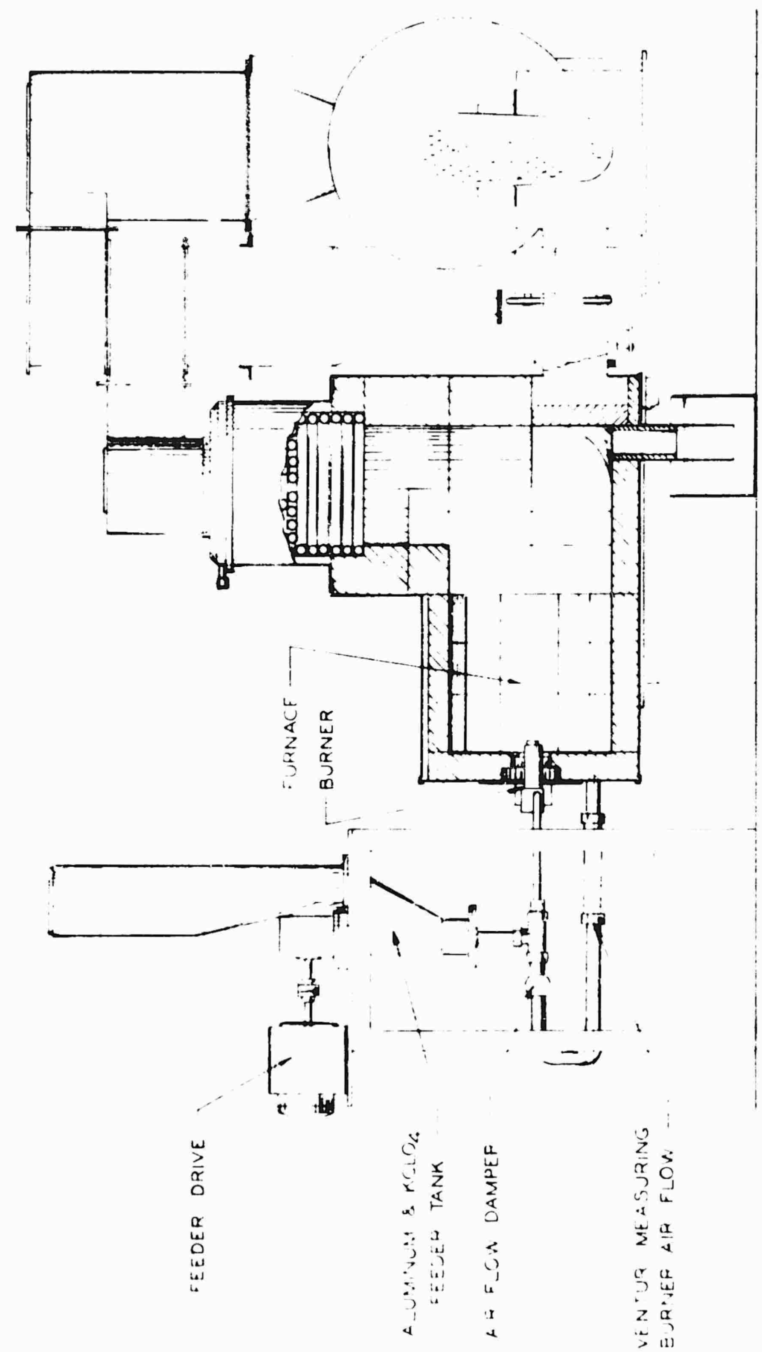
AEROJET ENGINEERING CORP
AZUSA, CALIFORNIA
TOLERANCES UNLESS OTHERWISE NOTED
5-2-50
R
AR 8812



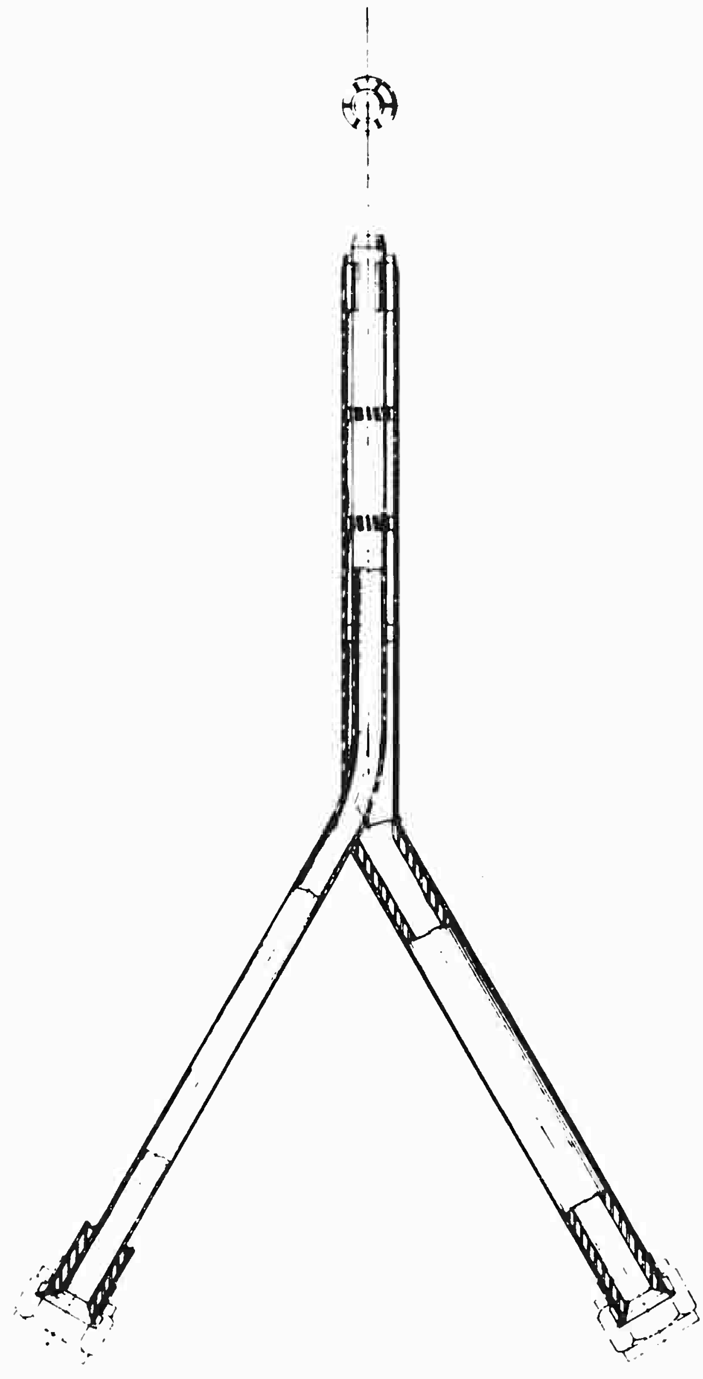
POWDERED ALCLO MIXTURE BURNER
EXTERNALLY MIXING

C-4225 MB

Figure 21



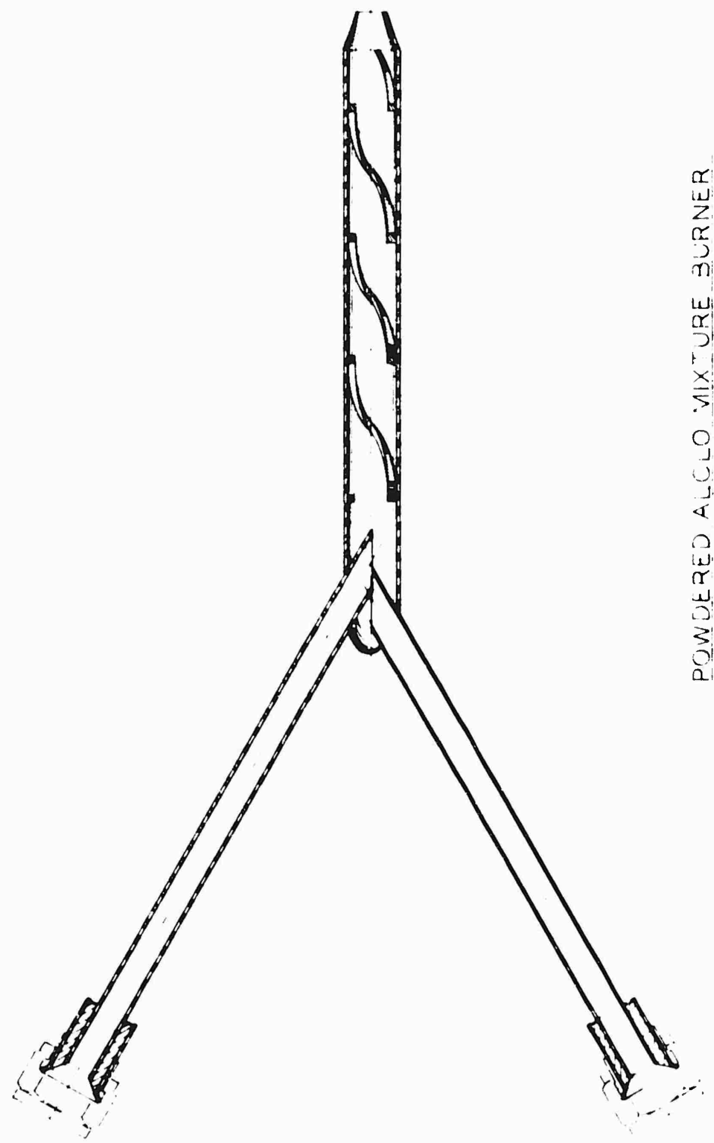
FINAL ARRANGEMENT OF EQUIPMENT
FOR BURNING POWDERED ALCLO MIXTURE IN TEST STEAM GENERATOR



POWDERED ALCLO MIXTURE BURNER
EXTERNALLY MIXING

C-4225 MB

Figure 21



POWDERED ALCLO MIXTURE BURNER
INTERNALLY MIXING

C-4228 9-18-53 MB

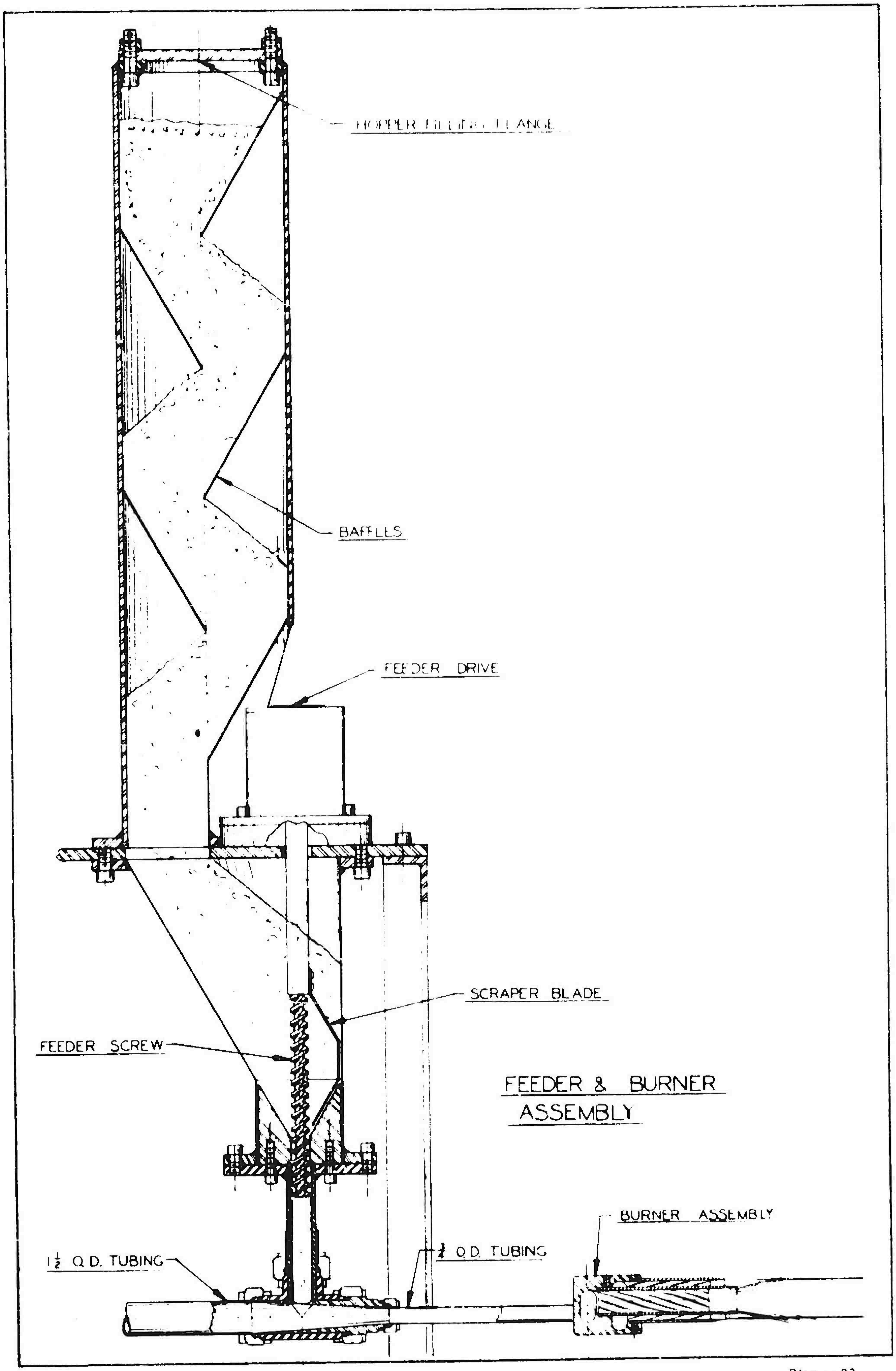
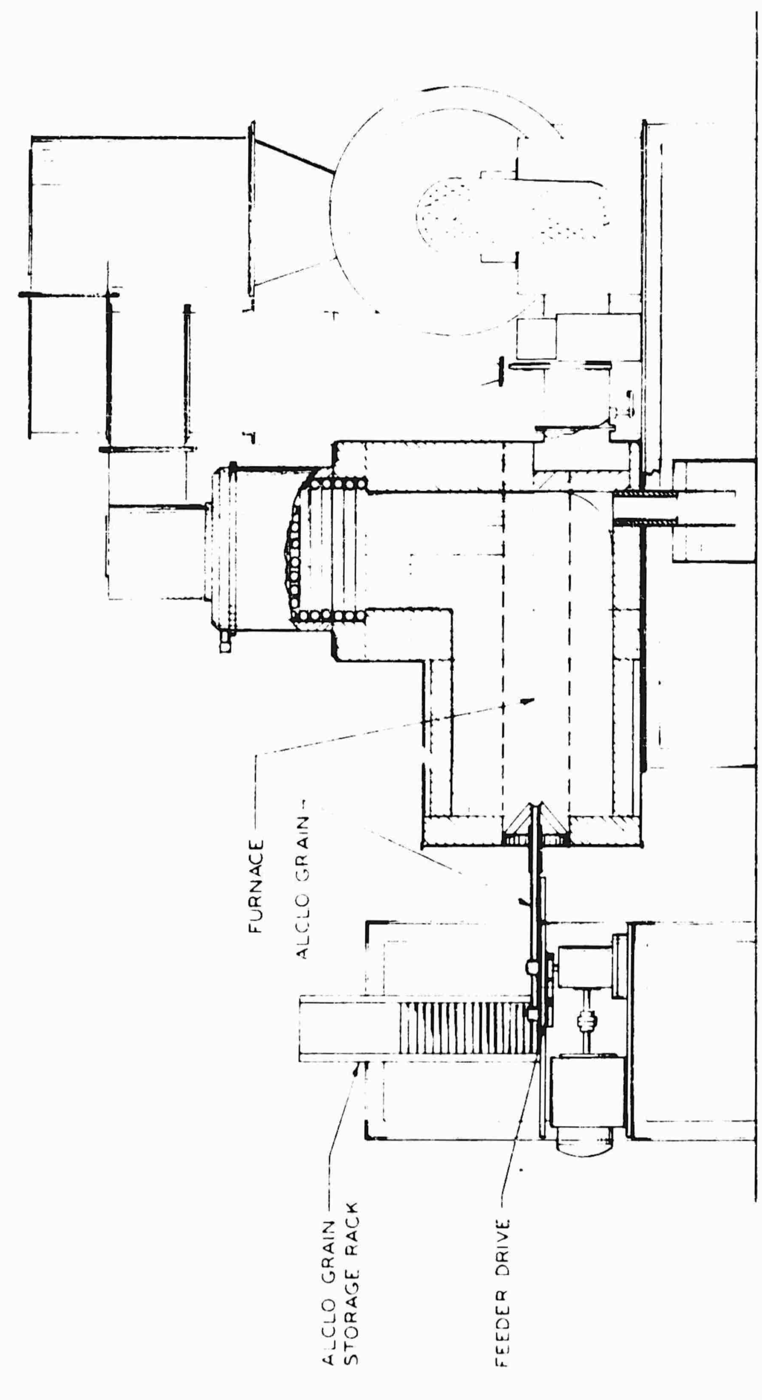

HOPPER FILLING FLANGE
BAFFLES
FEEDER DRIVE
SCRAPER BLADE
FEEDER SCREW
FEEDER & BURNER ASSEMBLY
BURNER ASSEMBLY
1 1/2 O.D. TUBING
3/4 O.D. TUBING

Figure 23



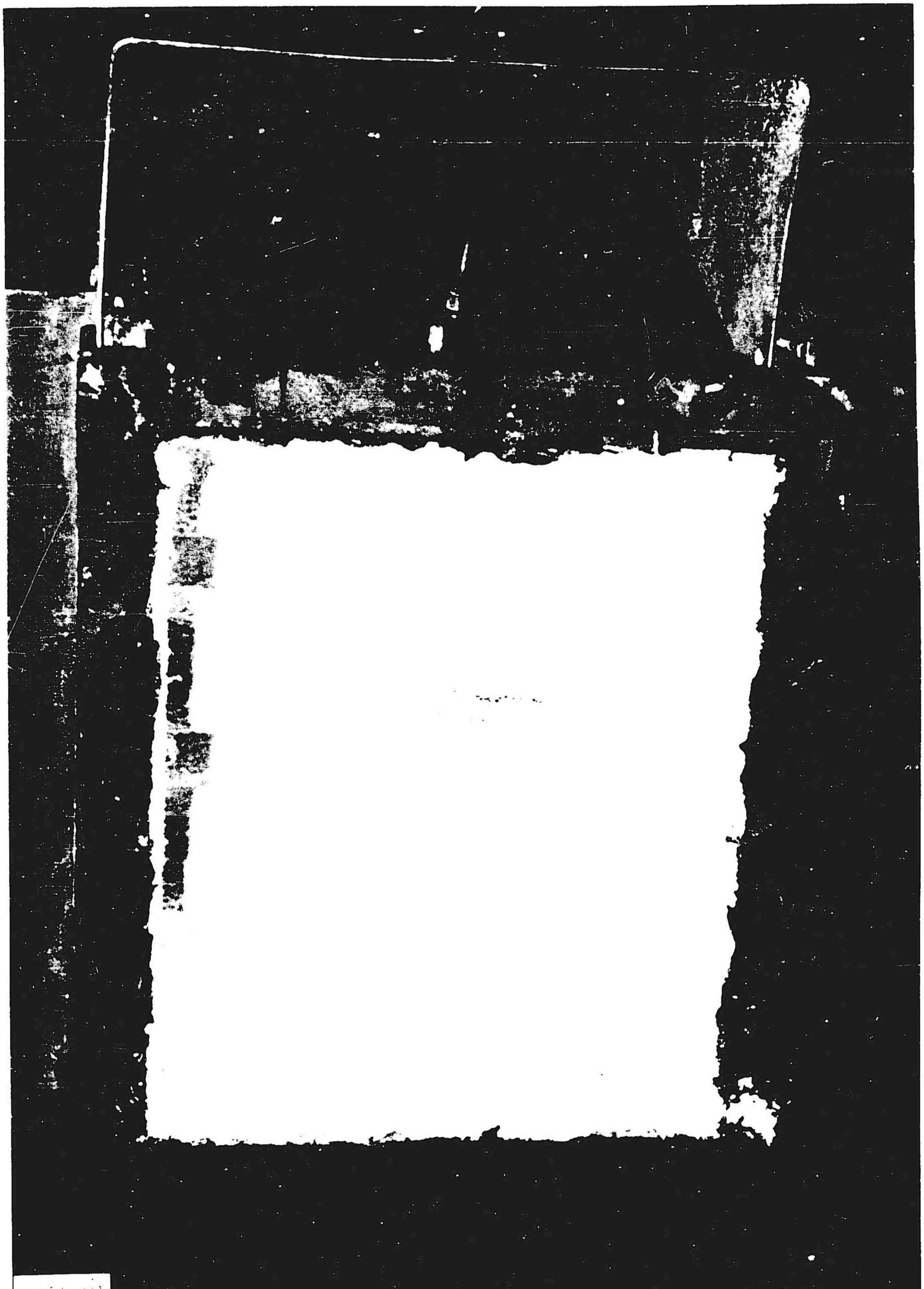
ARRANGEMENT OF EQUIPMENT
FOR BURNING SOLID ALCLO GRAINS IN TEST STEAM GENERATOR

C-4237

Figure 24

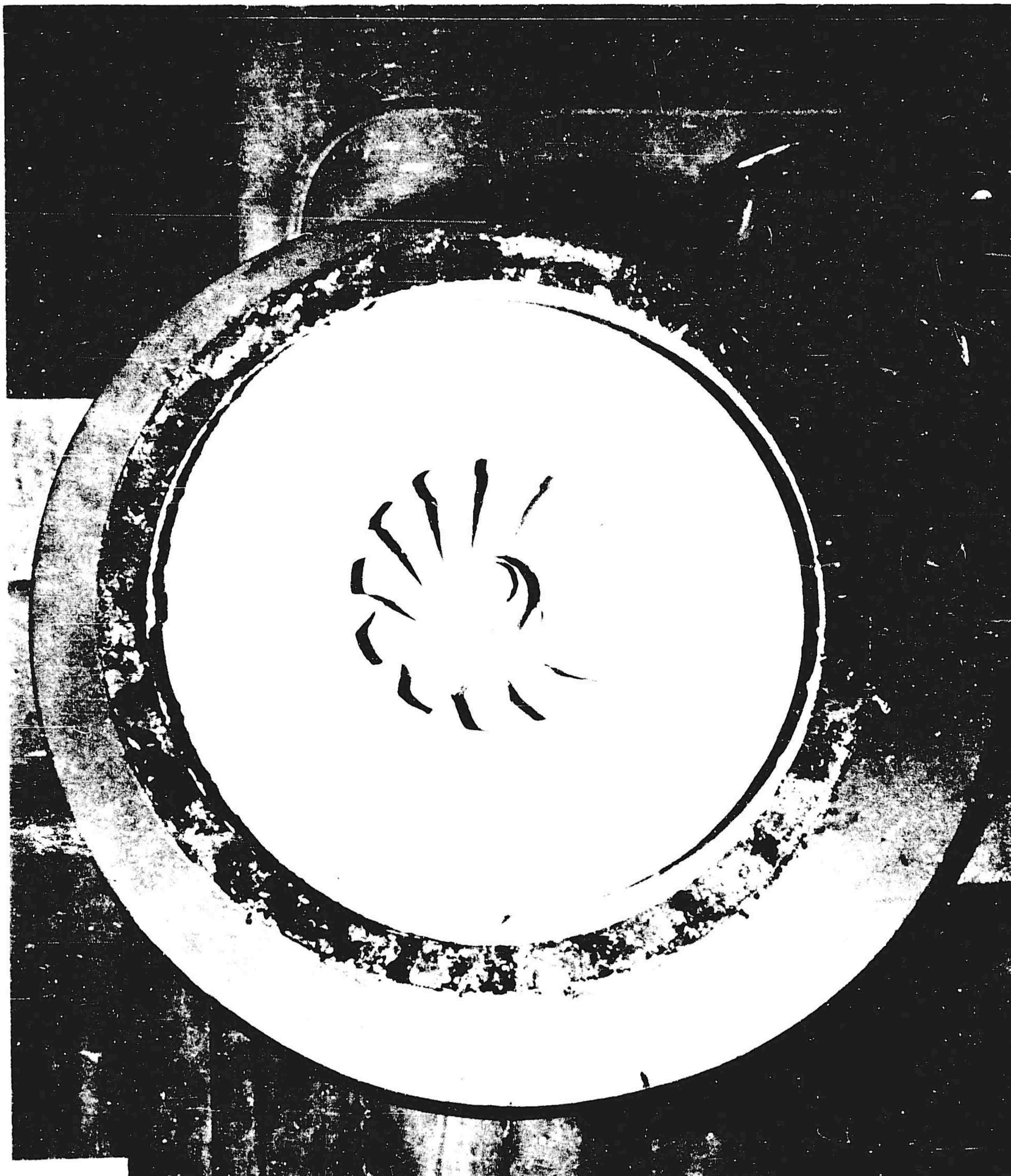
View of Boiler After Half-Hour of Closed-Cycle Operation

Figure 25



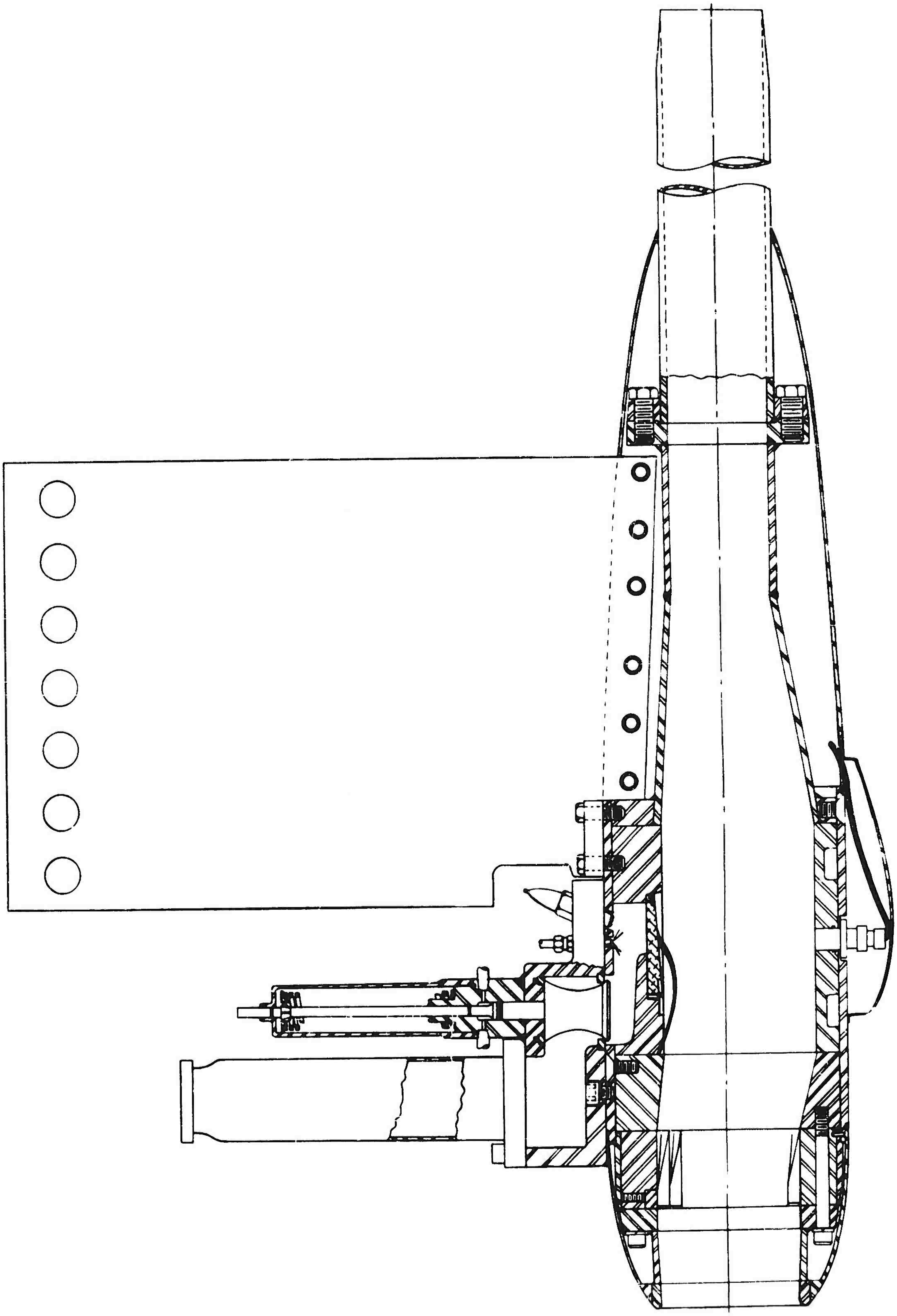
View of Dust Collector Inlet After Half-Hour of Closed Cycle Operation

Figure 26



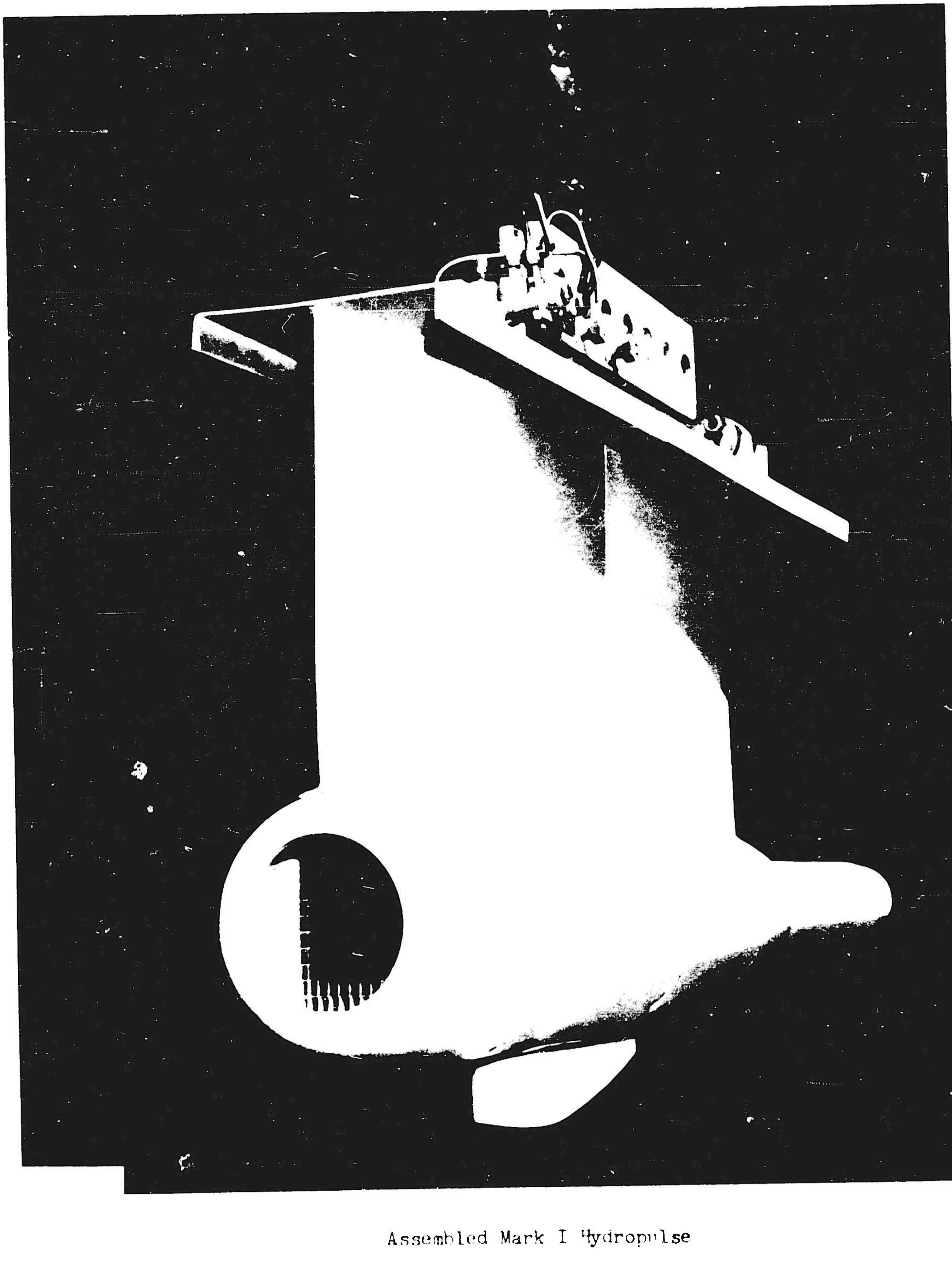
View of Recirculating Fan After Half-Hour of Closed-Cycle Operation

Figure 27



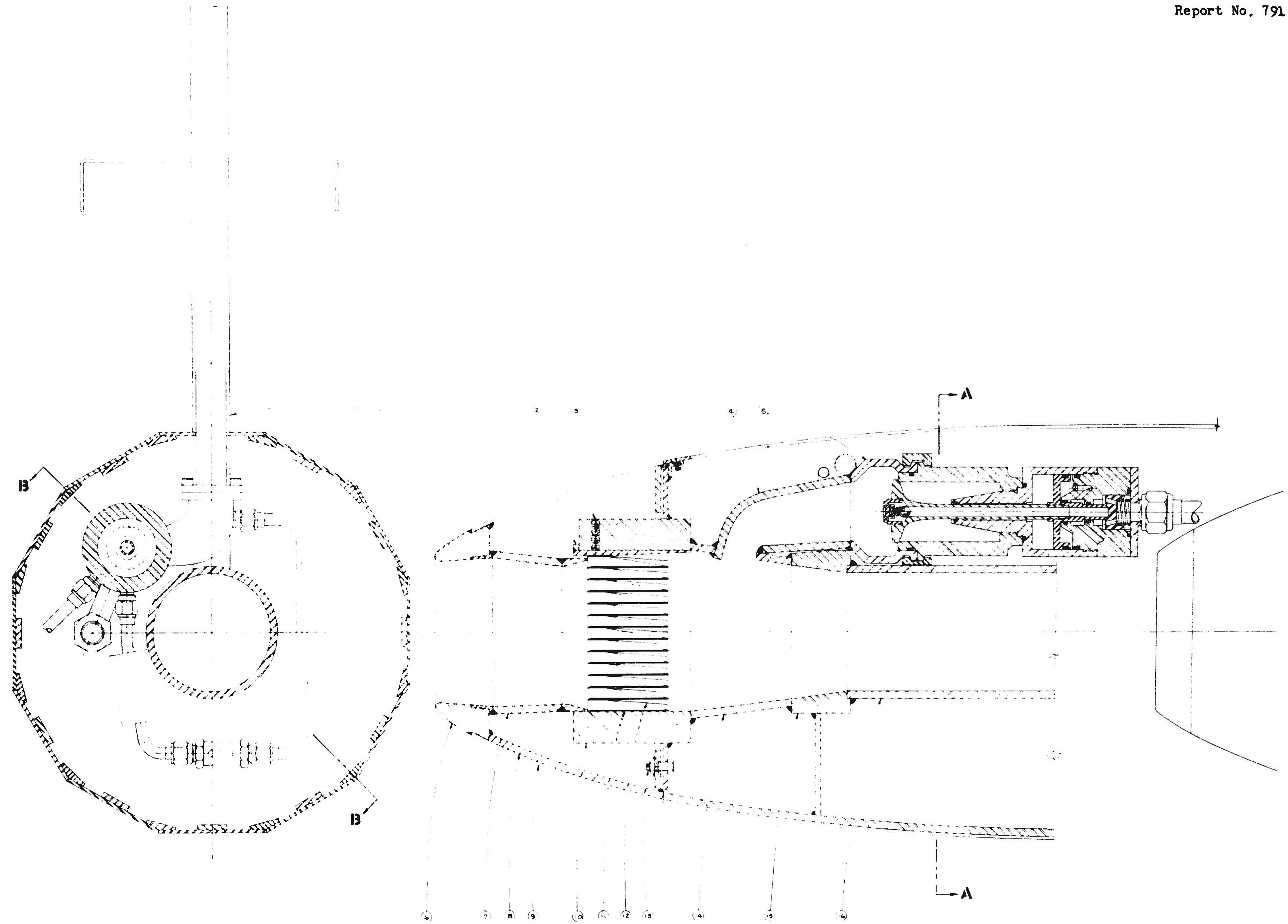
Gasoline - Compressed Air Hydropulse

Figure 28



Assembled Mark I Hydropulse

Figure 29

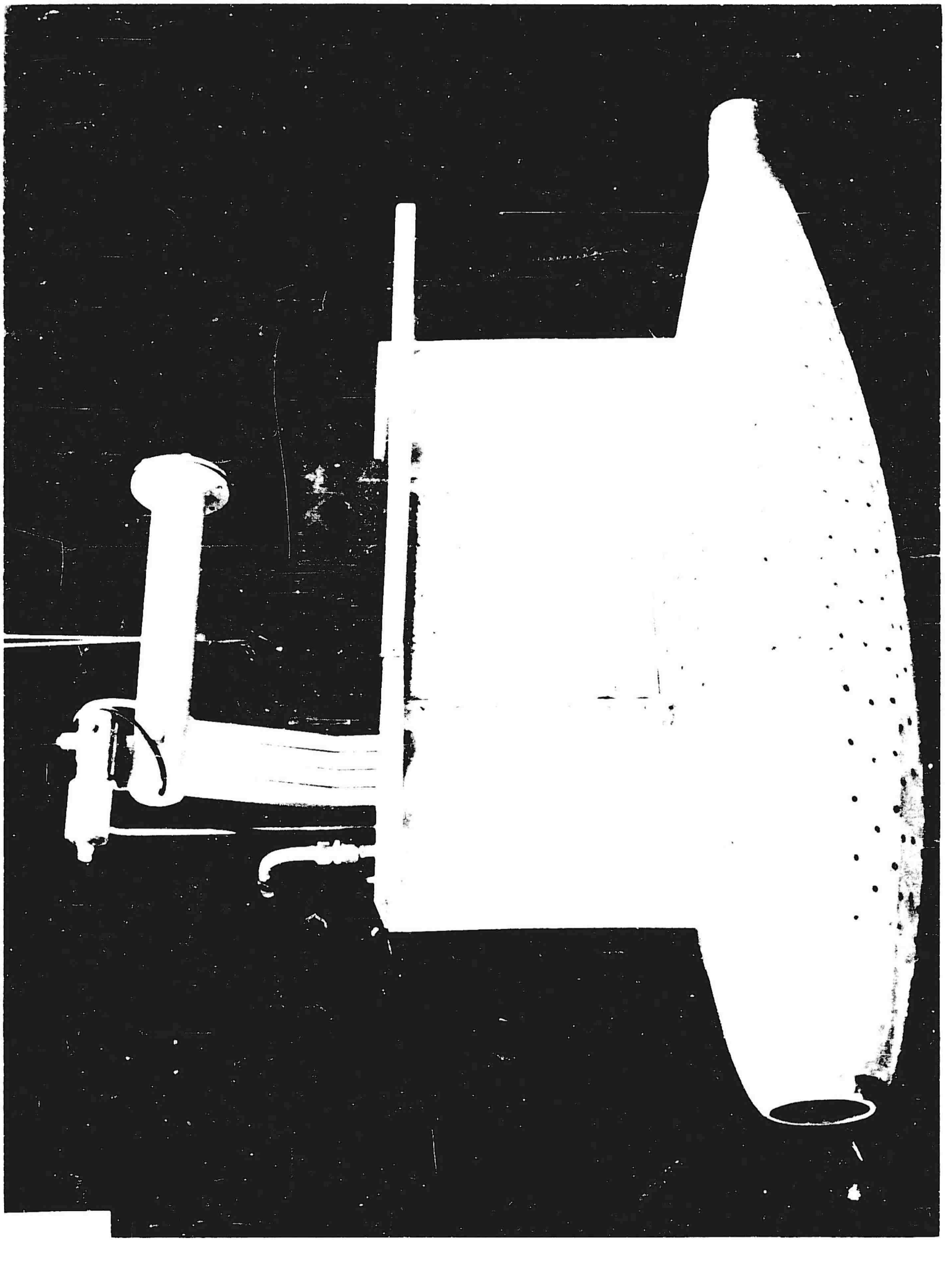


SECTION A-A

SECTION B-B

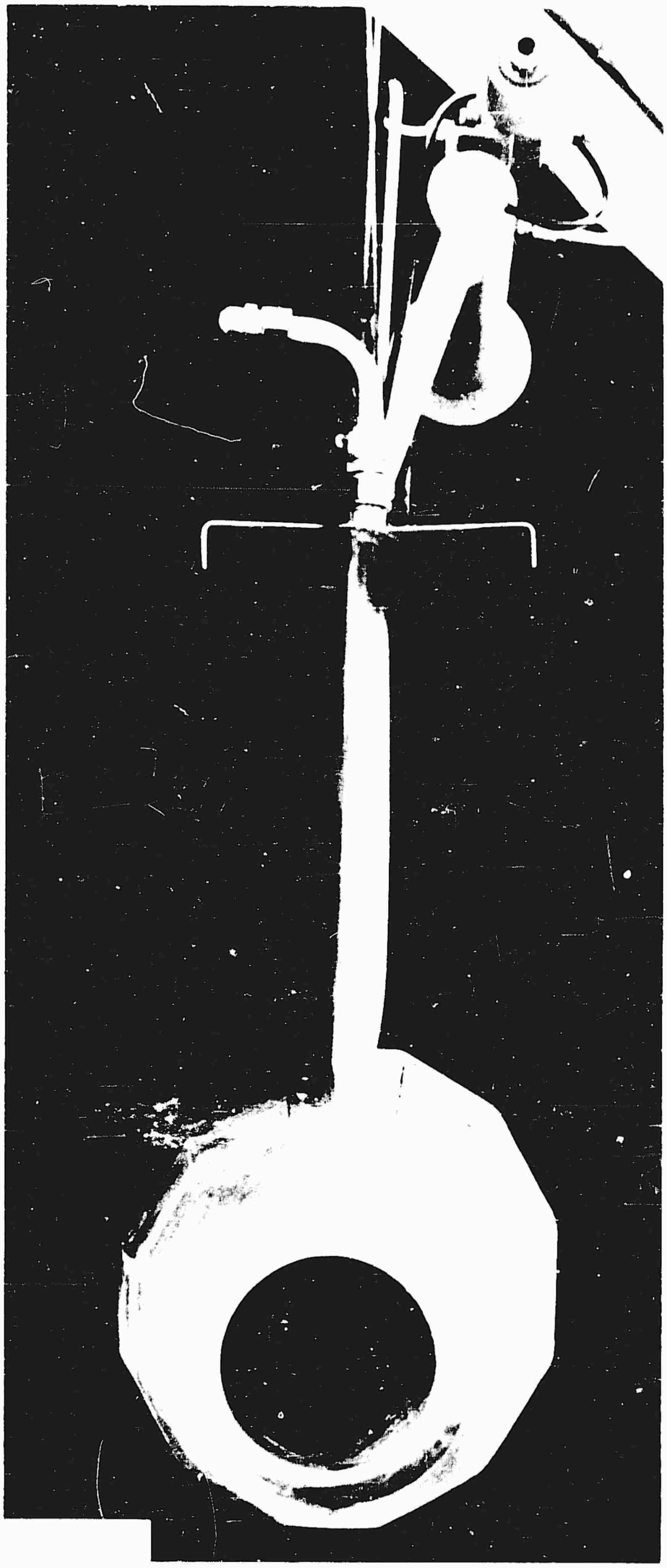
Mark II Gas-Air Hydropulse

Figure 30



Assembled Mark II Hydropulse

Figure 31



Assembled Mark II Hydropulse

Figure 32

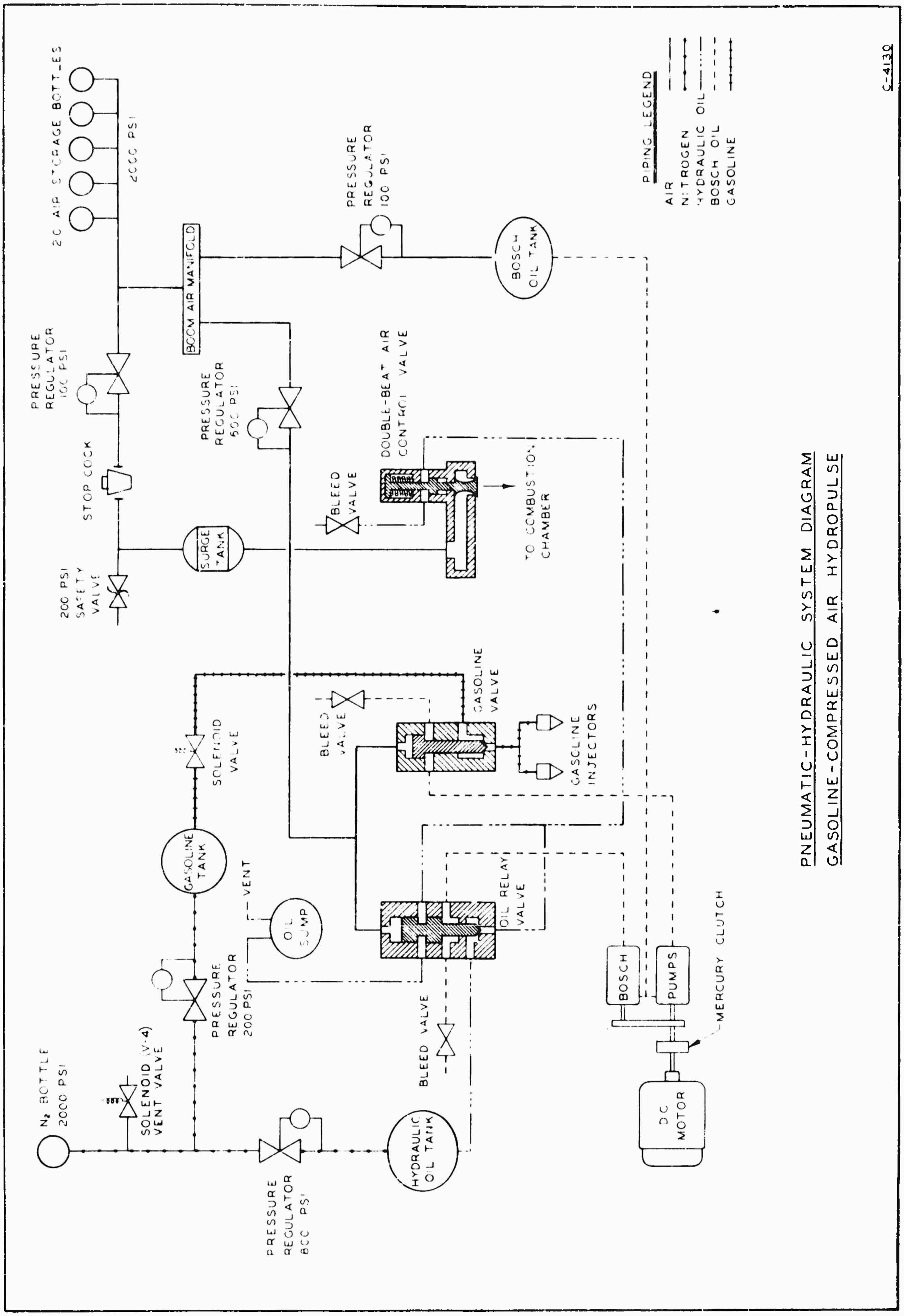

C-4130
PIPING LEGEND
AIR
NITROGEN
HYDRAULIC OIL
BOSCH OIL
GASOLINE
20 AIR STORAGE BOTTLES
2000 PSI
PRESSURE REGULATOR 100 PSI
BOOM AIR MANIFOLD
PRESSURE REGULATOR 100 PSI
BOSCH OIL TANK
STOP COCK
PRESSURE REGULATOR 600 PSI
DOUBLE-BEAT AIR CONTROL VALVE
BLEED VALVE
TO COMBUSTION CHAMBER
200 PSI SAFETY VALVE
SURGE TANK
GASOLINE VALVE
BLEED VALVE
GASOLINE INJECTORS
SOLENOID VALVE
GASOLINE TANK
VENT
OIL SUMP
OIL RELAY VALVE
MERCURY CLUTCH
BOSCH
PUMPS
PRESSURE REGULATOR 200 PSI
BLEED VALVE
N_2 BOTTLE 2000 PSI
SOLENOID (V-4) VENT VALVE
DC MOTOR
HYDRAULIC OIL TANK
PRESSURE REGULATOR 800 PSI
PNEUMATIC-HYDRAULIC SYSTEM DIAGRAM
GASOLINE-COMPRESSED AIR HYDROPULSE

Figure 33

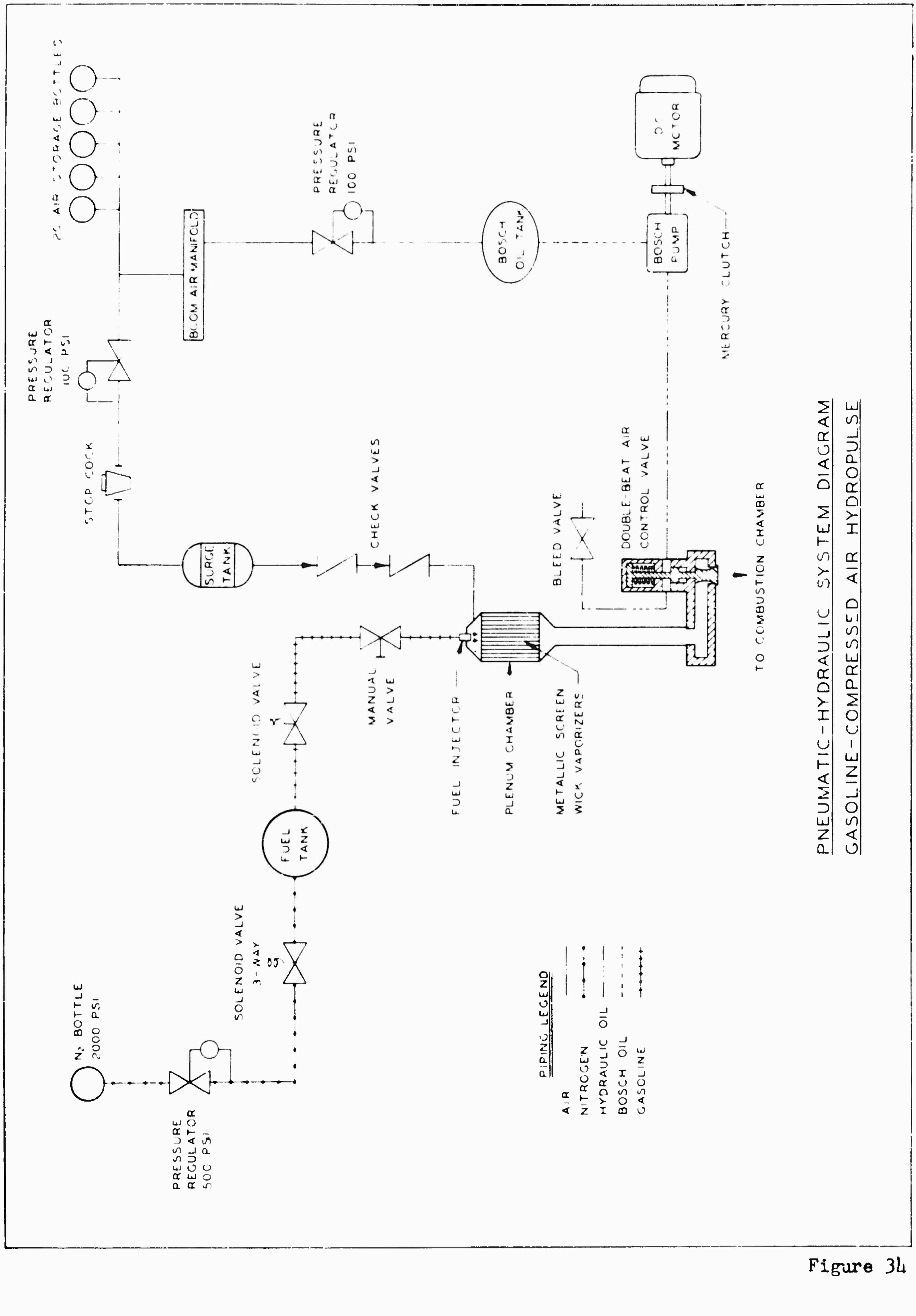
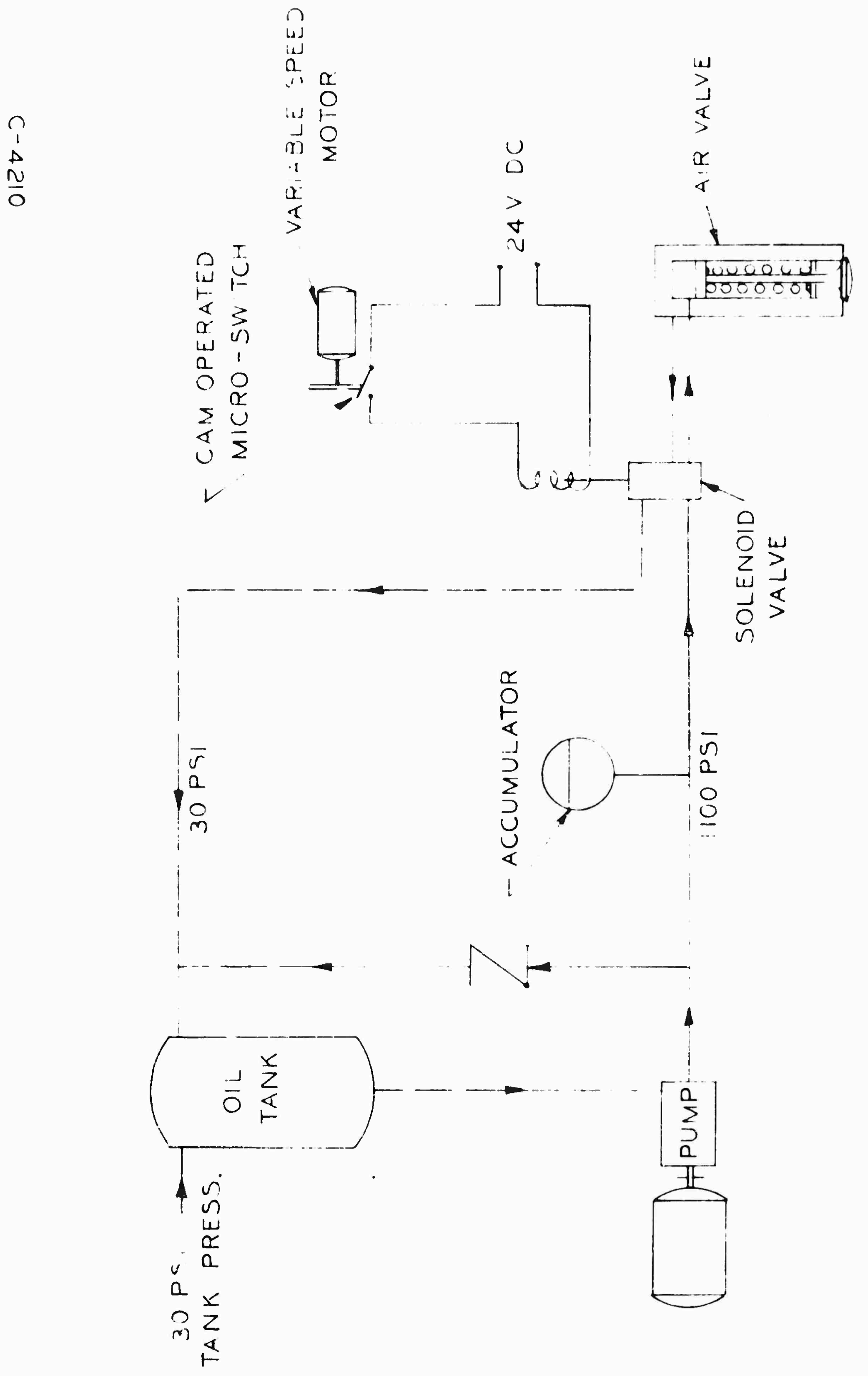

PNEUMATIC-HYDRAULIC SYSTEM DIAGRAM
GASOLINE-COMPRESSED AIR HYDROPULSE
AIR STORAGE BOTTLES
BOOM AIR MANIFOLD
PRESSURE REGULATOR 100 PSI
PRESSURE REGULATOR 100 PSI
BOSCH OIL TANK
BOSCH PUMP
DC MOTOR
MERCURY CLUTCH
STOP COCK
SURGE TANK
CHECK VALVES
DOUBLE-BEAT AIR CONTROL VALVE
BLEED VALVE
TO COMBUSTION CHAMBER
SOLENOID VALVE
MANUAL VALVE
FUEL INJECTOR
PLENUM CHAMBER
METALLIC SCREEN WICK VAPORIZERS
FUEL TANK
SOLENOID VALVE 3-WAY
N_2 BOTTLE 2000 PSI
PRESSURE REGULATOR 500 PSI
PIPING LEGEND
AIR
NITROGEN
HYDRAULIC OIL
BOSCH OIL
GASOLINE

Figure 34



SCHEMATIC DIAGRAM
HYDRAULIC VALVE ACTUATING SYSTEM

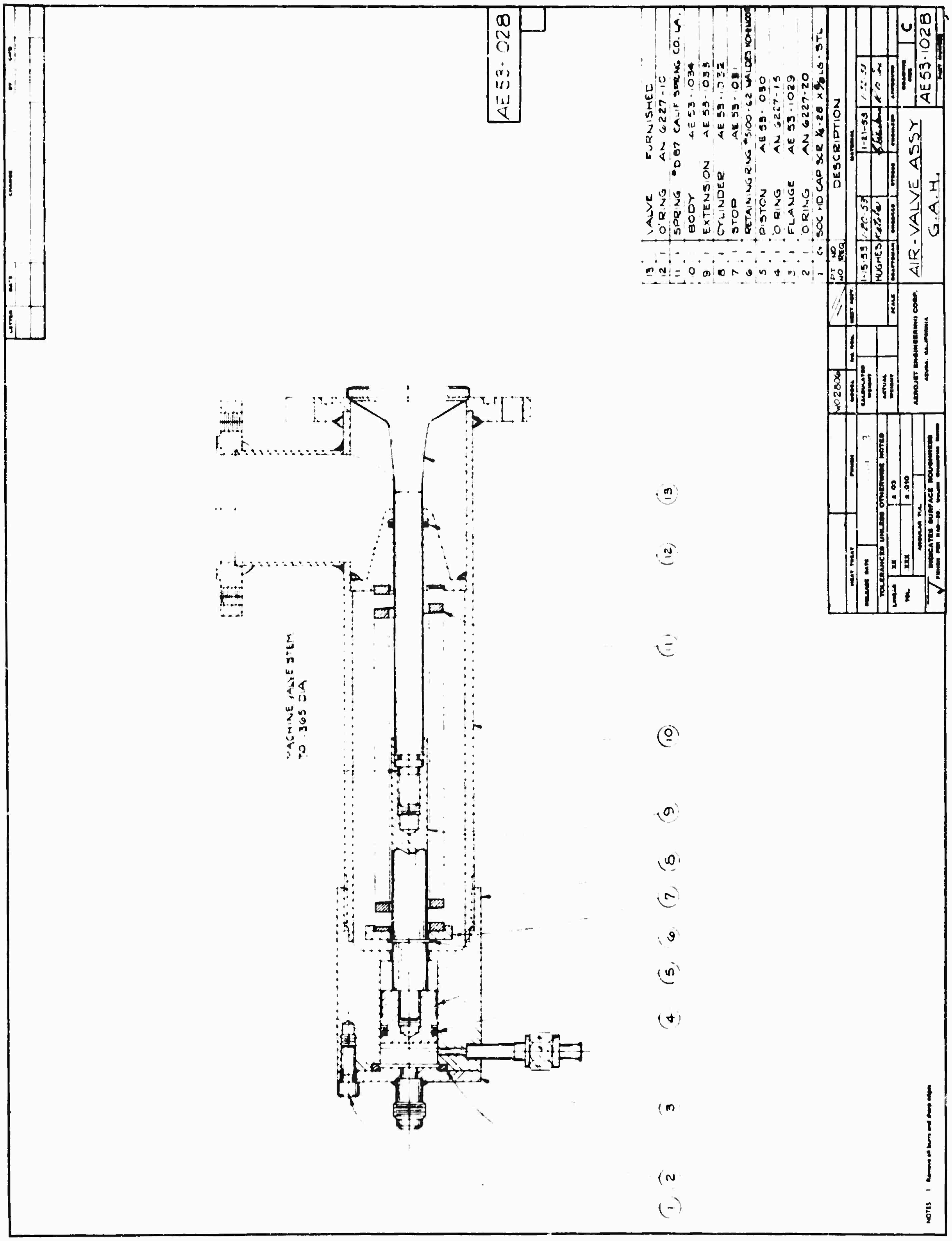

AE 53-1028
VALVE FURNISHED
SPRING #D87 CALIF SPRING CO. L.A.
BODY
EXTENSION
CYLINDER
STOP
RETAINING RING
PISTON
O RING
FLANGE
O RING
DESCRIPTION
AIR-VALVE ASSY
G.A.H.
AEROJET ENGINEERING CORP.
MACHINE VALVE STEM TO .365 DIA
TOLERANCES UNLESS OTHERWISE NOTED

Figure 36

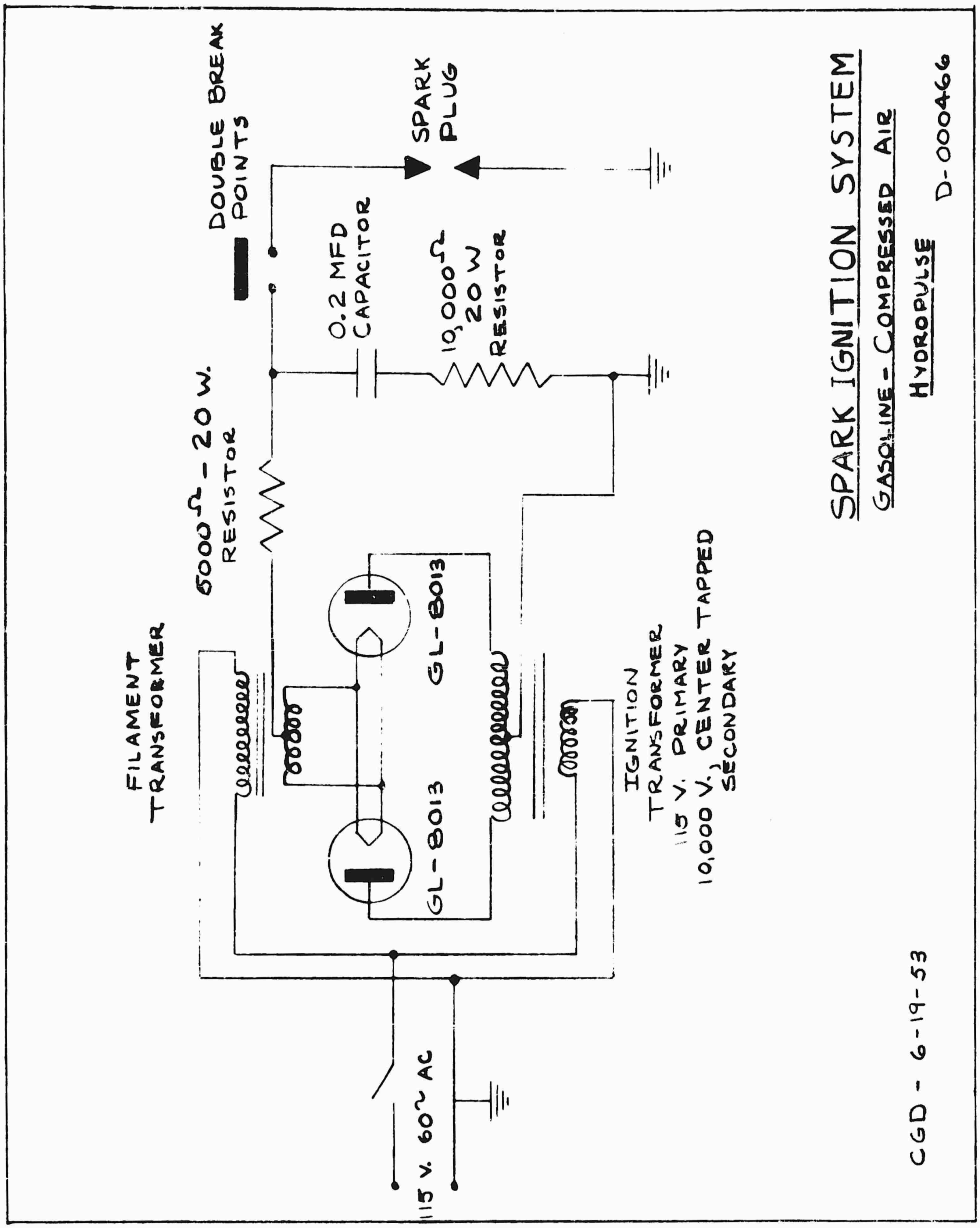
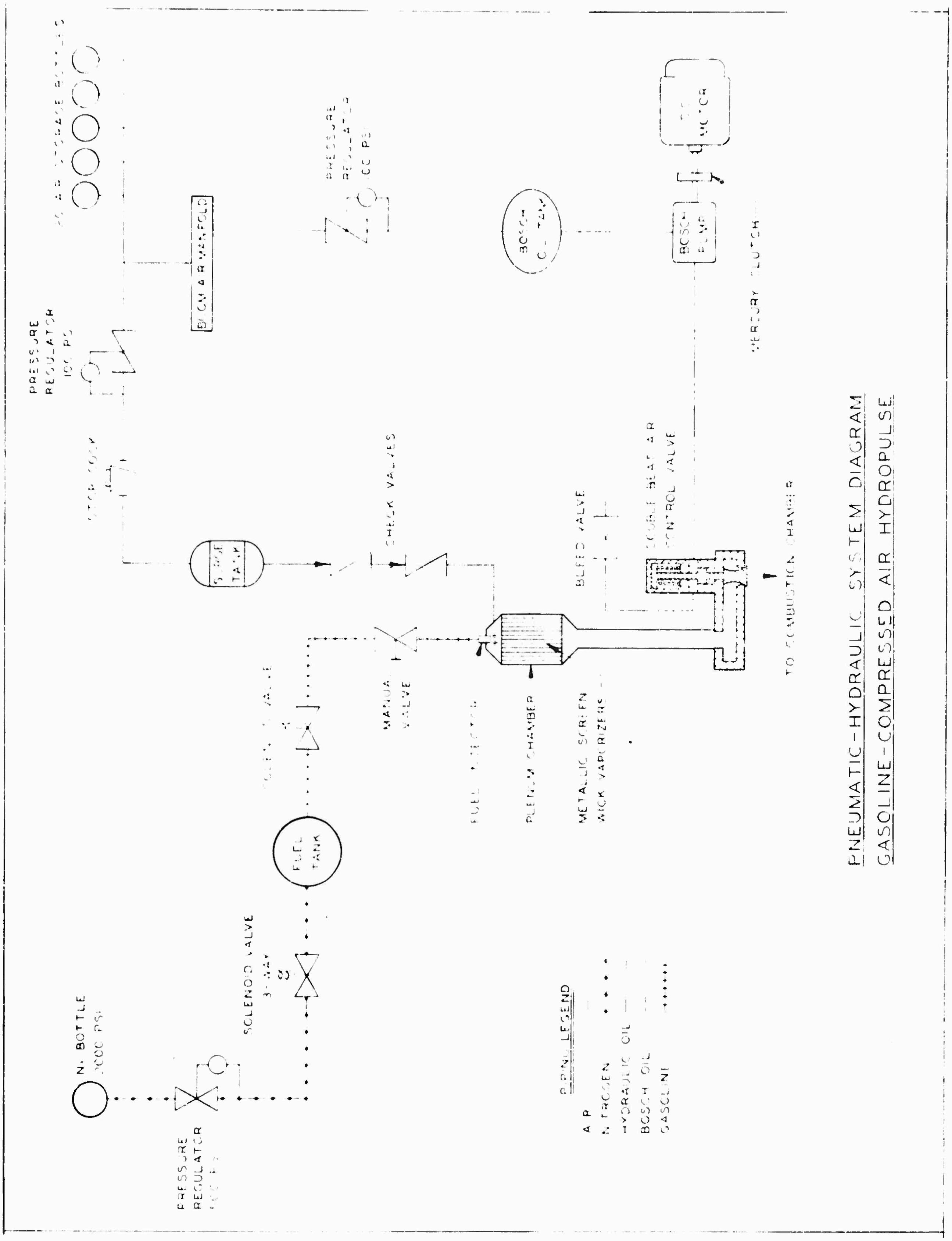

SPARK IGNITION SYSTEM
GASOLINE - COMPRESSED AIR
HYDROPULSE
D-000466
DOUBLE BREAK POINTS
SPARK PLUG
0.2 MFD CAPACITOR
10,000 Ω 20 W RESISTOR
5000 Ω - 20 W. RESISTOR
GL-8013
GL-8013
FILAMENT TRANSFORMER
IGNITION TRANSFORMER
115 V. PRIMARY
10,000 V., CENTER TAPPED SECONDARY
115 V. 60~ AC
CGD - 6-19-53

Figure 37



PNEUMATIC-HYDRAULIC SYSTEM DIAGRAM
GASOLINE-COMPRESSED AIR HYDROPULSE

Figure 38

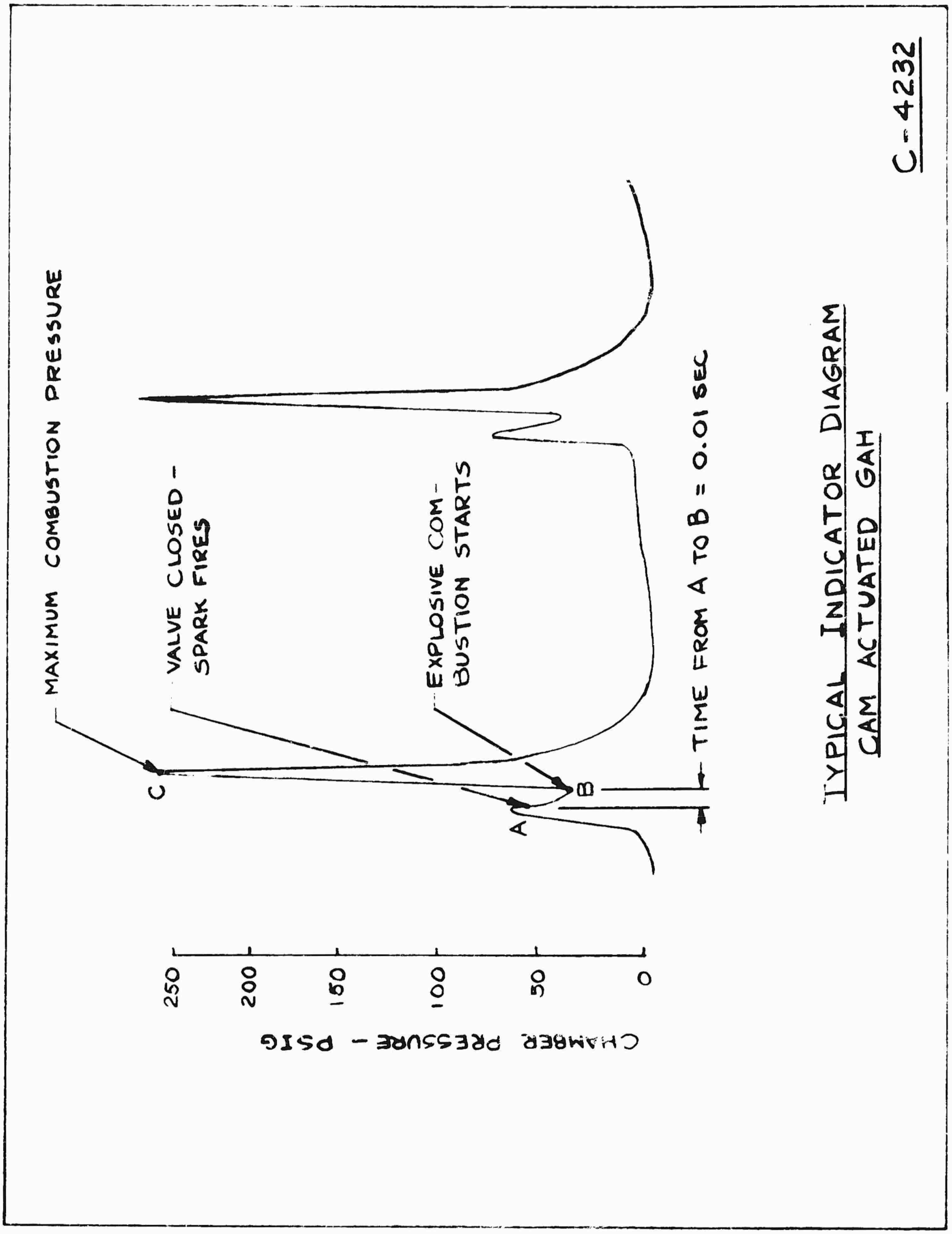
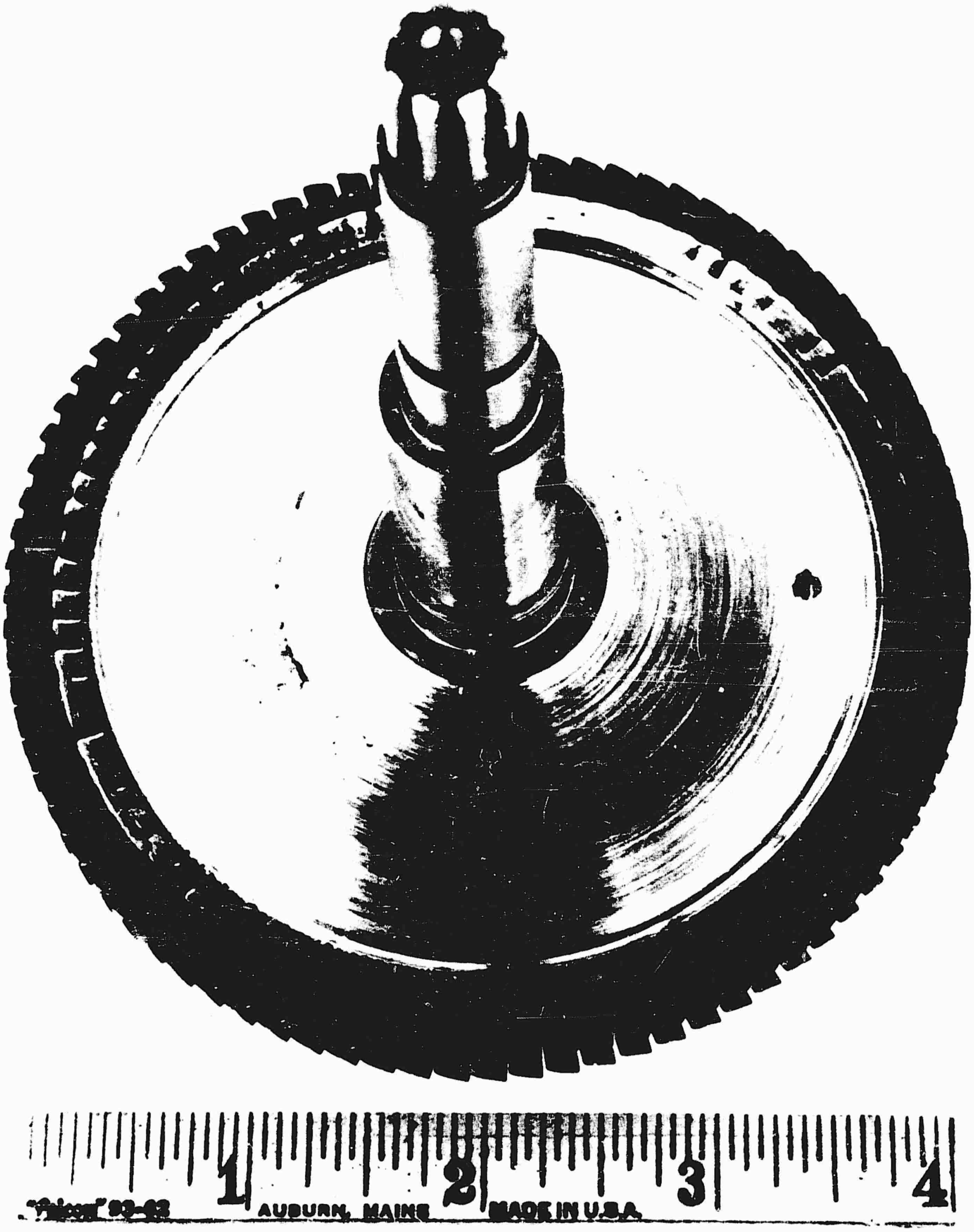

C-4232
MAXIMUM COMBUSTION PRESSURE
VALVE CLOSED -
SPARK FIRES
EXPLOSIVE COM-
BUSTION STARTS
TIME FROM A TO B = 0.01 SEC
C
B
A
250
200
150
100
50
0
CHAMBER PRESSURE - PSIG
TYPICAL INDICATOR DIAGRAM
CAM ACTUATED GAH

Figure 39



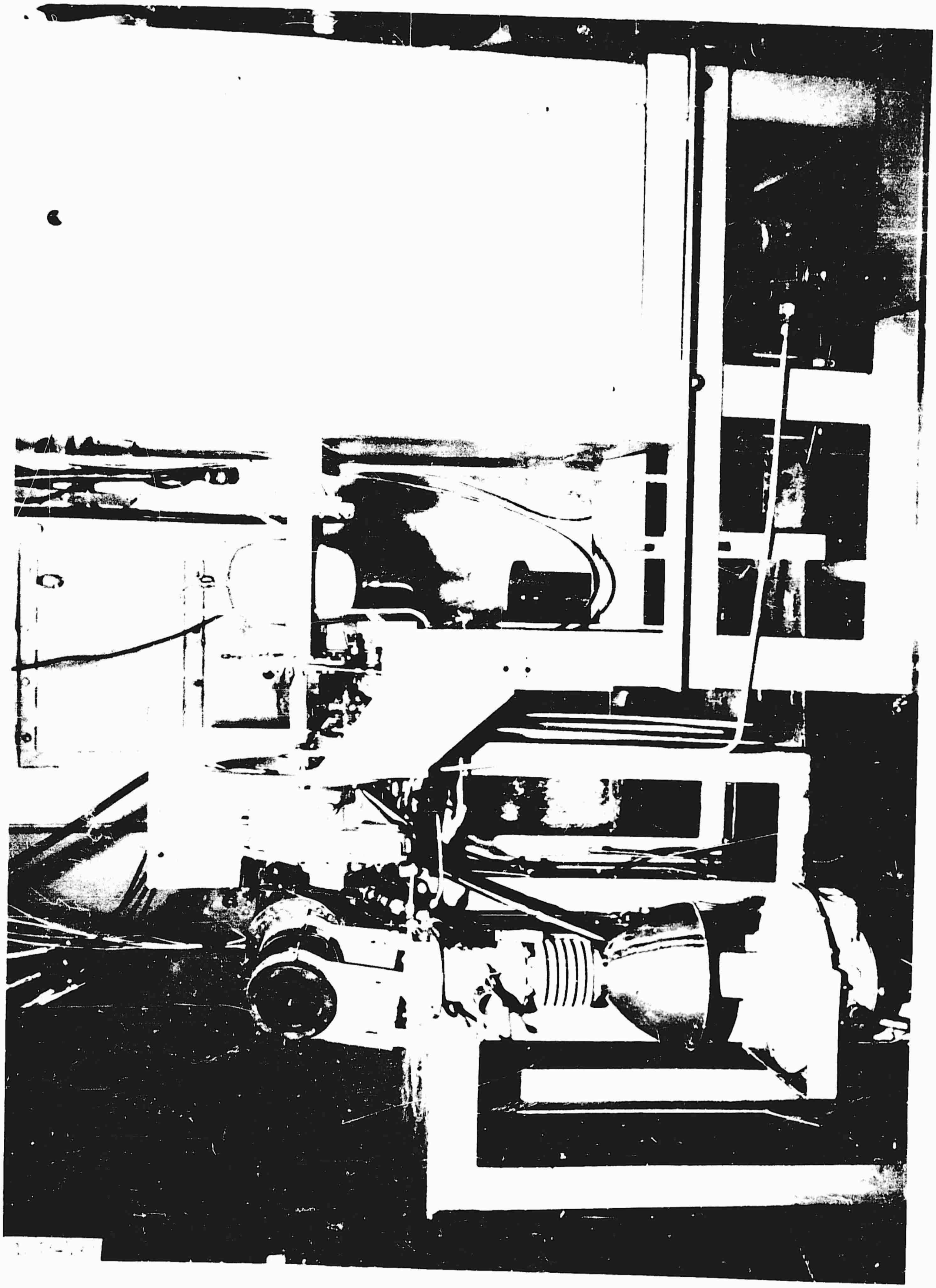
1253-598

Turbine Wheel for Solid-Propellant Torpedo Power Plant

Figure 40

Turbine, Gas Generator, and Gearbox Installation

Solid-Propellant Grain and Igniter



Test-Pit Installation for Solid-Propellant Torpedo Engine

Figure 43

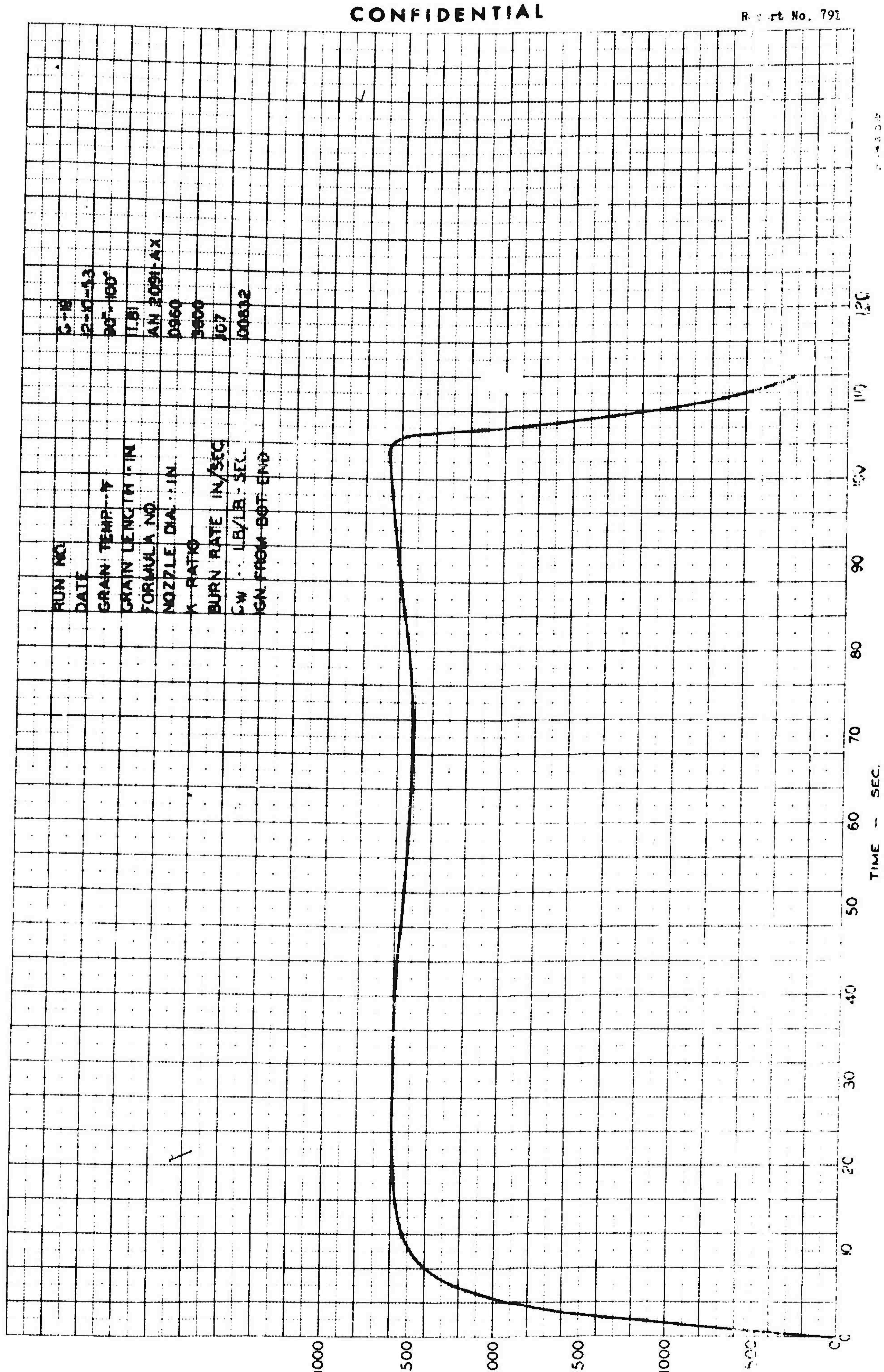

RUN NO.
DATE
GRAIN TEMP. °F
GRAIN LENGTH - IN
FORMULA NO.
NOZZLE DIA. - IN.
K RATIO
BURN RATE IN/SEC
Cw - LB/LB - SEC.
IGN. FROM BOT. END
2-10-53
11.81
AN 2091-AX
107
00832
TIME - SEC.
10
20
30
40
50
60
70
80
90
110
CHAMBER PRESS. PSI
3000
2500
2000
1500
1000

Figure 44